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RESEARCH ARTICLE

ANALYSIS OF PUBLIC DRINKING WATER QUALITY ALONG WATER DISTRIBUTION SYSTEMS IN ADDIS ABABA CITY

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ABSTRACT: In this study, the impact of physical parameters and disinfection on the availability of bacteria in treated water delivered to Addis Ababa residents was assessed. Thirty-four water samples were purposively collected from different points and physico-chemical and bacteriological parameters were analyzed following standard methods. The results showed that all physico-chemical parameters analyzed were in the standard ranges of the World Health Organization (WHO) and Ethiopian National Standards (ENS) whereas residual chlorine (0.2–0.7 mg/l) were not within the limit set by WHO and ENS at a few sampling points. Regarding bacteriological parameters, significant number of coliforms (TC (3–299 CFU/100 ml) and FC (2–36 CFU/100 ml) and HPC (26–308 CFU/ml) were detected at all sampling sites although residual chlorine was maintained. Moreover, HPC was significant positive correlation with TC (r = 0.934 at P value of 0.01 and r = 0.599, at P value of 0.05) and FC (r = 0.614 and a significant negative correlation with RCl (r = -0.620 at P value and r = -0.792 both at P value=0.01). On the other hand, TC and FC had a significant positive correlation with each other (r = 0.643 and r = 0.811 both at P =0.01) and significant negative correlation with RCl (r = -0.638 and r = -0.614) and (r = -0.545 and r = -0.094), respectively. The study indicated that residual chlorine in some sample sites might not be efficient in killing microbes and there might be regrowth of microbes along the various distribution systems in the supply lines.

Key words/phrases: Coliforms, Disinfection, Distribution systems, Drinking water, Residual chlorine.

INTRODUCTION

Safe drinking water is fundamental to health and its supply for the public at large should be supported with proper infrastructure sanitation (Zin *et al*., 2013). Access to safe drinking water reduces potential disease-causing organisms and water-borne diseases. According to WHO and UNICEF

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(2017), 4.7 billion people used piped water supplies and two of the five people in rural and four of five people in urban areas used piped water supplies globally in 2015. In Ethiopia during the same year, 86% of the urban population used piped water supplies.

However, quality of drinking water gets poorer in water distribution system due to leakage through corrosion of pipes, intrusion of microbial contaminants and regrowth, disinfection failure, inadequate disinfection residual, low water pressure in pipes, excessive network leakages and poor disposal of wastes (Karikari and Ampofo, 2013). As a result, more than 2 billion people in urban areas worldwide are affected by the presence of complex microbial assemblages and water-borne pathogens found in the drinking water supply systems (WHO and UNICEF, 2017).

In developing countries, microbiological contamination of drinking water is the critical concern that puts the health of people at high risk. The formation of biofilms inside the wall of pipelines normally serve as an ideal shield for coliform bacteria and other microbes within the distribution systems against the action of disinfection and hence increasing the density of heterotrophic count (HPC) and coliforms in tap water within the distribution systems (Qaiser *et al*., 2014).

Moreover, high densities of these indicator organisms in treated water both in the household storage tanker and tap water sample sites raised the health risk regarding the opportunistic pathogens that are potentially harboured in the water distribution system (Mulamattathil *et al*., 2015). This also plays a key role in the deterioration of the quality of drinking water distributed even after treatment (Tadesse Sisay *et al*., 2017). In Ethiopia, poor quality drinking water and inadequate water supply contributes to more than 50% of communicable diseases (Solomon Abera *et al*., 2011).

Addis Ababa is the largest city in Ethiopia with a total population of 3.5 million based on the population projection (2014–2017) of Central Statistical Agency of Ethiopia (CSA, 2014). The rapid population growth and expansion of the city around contributes to limit not only the capacity of water supply utility but also the efficiency of sewage discharging systems.

Previous studies showed that contamination of drinking water is very high due to the old cross-connected distribution systems and point of use at the household level that causes water borne diarrhea in the city (Dawit Mekonnen, 2015; Metadel Adane *et al*., 2017). Moreover, Amsalu Wolde *et al*. (2020) showed positive results of total and fecal coliforms in the study conducted by collecting municipal drinking water samples.

However, there is no sufficient work done on the quality of drinking water supplied through distribution systems with respect to the impact of various physical parameters and disinfectant used in the treatment process and hence there is a need for more information on the quality of water based on different physical parameters, residual chlorine and indicator organisms (total coliforms (TC), fecal coliforms (FC) and heterotrophic bacteria (HPC)) in drinking water distribution systems starting from source up to household point of use. Therefore, this study was intended to investigate the status of water quality of chlorine treated water at different points from the distribution system and at household point of use sites.

MATERIALS AND METHODS

Study site description

The study was conducted in Addis Ababa city, the capital of Ethiopia, where two drinking water treatment plants receive surface water sources for water supply to some parts of the city. Addis Ababa city located between 8° 45′ to 9° 13′ North latitude and 38° 34′ to 39° 4′ East longitude and lies at an elevation of 2,300 m asl, has humid subtropical highland climate and grassland biome. There are two surface water treatment plants located at the outskirts of the city where they receive surface water from Legedadi and Gefersa dams, treating and delivering potable water to the city.

Study design

In this study cross sectional, descriptive and quantitative approach was employed to investigate the impact of physical factors on the presence of indicator bacteria and the correlation analysis of physico-chemical parameters and indicator microbes across the distribution systems following the supply lines. The study was conducted from June to August 2015. Water samples were collected from source water entering to treatment plants, finished water leaving treatment plants, reservoir samples and from household storage tanker and tap water samples. Both culturing of indicator microbes in the laboratory and field-based measurement of physical parameters and residual chlorine was employed to analyze the influence of parameters on the existence of these microbes. The impact of residual chlorine on the availability of indicator bacteria in drinking water was also measured at the time of sample collection in the field.

Sample collection

Purposive sampling technique was employed to select sampling sites across the distribution lines based on sampling procedures of Standard Methods of World Health Organization for Water and Waste Water Examination (WHO, 2017). Water samples were categorized based on type of source as raw source water, finished water, reservoir water, household tap and storage tanker water. From these categories, 34 water samples (4 from treatment plants - 2 source water, LS, GS; 2 finished water, LF, GF), 7 samples from reservoirs (2 from Gefersa TP and 5 from Legedadi TP lines) and 23 samples from various household taps (11 from Legedadi TP and 12 from Gefersa TP distribution lines) were purposively and proportionally collected to represent the geographical distribution of the study area and the categories of different water sources. The samples were collected in triplicate every 20 days interval from June to August 2015. Five hundred millilitres of water were collected for cultivation-based analysis from Legedadi (LS, LF) and Gefersa (GS, GF) drinking water treatment plants, reservoirs (LR1, LR2, LR3, LR4, LR5, GR1 and GR2) and from household point of use taps (faucets) (LT1, LT2, LT3, LT4, LT5, LT6, GT1, GT2, GT3 and GT4) and household point of use storage tankers (LS1, LS2, LS3, LS4, LS5, GS1, GS2, GS3, GS4, GS5,GS6, GS7 and GS8) following lines of distribution systems (Fig. 1).

Sample analysis methods

Physico-chemical water quality parameter analysis

Temperature, pH, conductivity, and TDS were measured at sample collection site using a portable pH 10 series meter (Oakton Instruments, Vernon Hills, IL) at the time of sample collection. Similarly, residual chlorine was measured using HACH DPD colorimetric method on a HACH DR890 colorimeter following standard method of drinking water quality assessment at the time of sample collection.

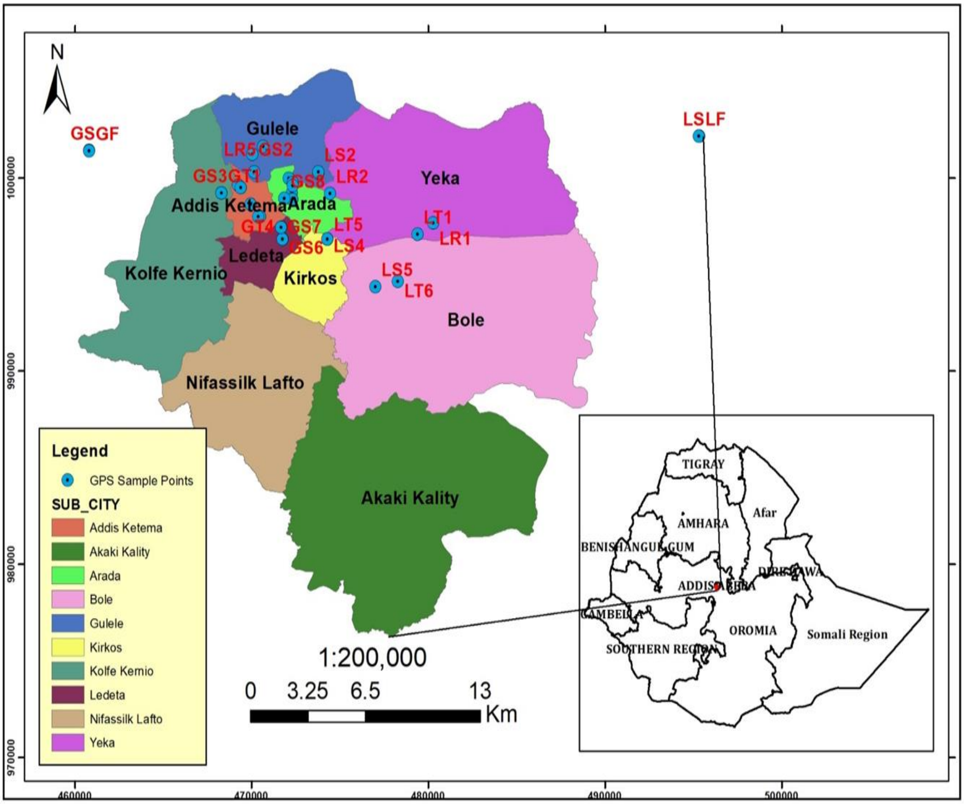


Fig. 1. A map of sampling locations indicating the two treatment plants (Gefersa (GS, GF-left) and Legedadi (LS, LF-right)). Thirty-four sampling locations are on the map but about 14 sample codes are invisible since points are overlapped on one another.

Bacteriological water quality indicator analysis

Total and fecal coliform culture

Total coliform (TC), fecal coliform (FC) and heterotrophic bacteria plate count (HPC) were analyzed by membrane filtration technique using cellulose acetate membrane having a pore size of 0.45 µm. Hundred millilitres of water sample were poured to the filter funnel containing cellulose acetate membrane with pore size of 0.45 µm and pumped down by the help of vacuum pump. The absorbent pads were placed on to the base of aluminum Petri-dish containing Membrane Lauryl Sulphate Broth (MLSB) as cultivation media. The plates were incubated at 37°C and 45°C for about 24 hours to detect total coliforms and fecal coliforms, respectively.

Heterotrophic bacteria plate count

Heterotrophic bacteria plate count (HPC) was also determined by same membrane filtration technique by preparing R2A agar as growth media based on standard methods. Hundred millilitres of diluted water (1 ml sample water was diluted to 99 ml buffered dilution water) was filtered through 0.45 µm pore size sterile membrane filter and was placed on to a 50 x 9 mm Petri-dish filled with 15 ml of the liquified R2A agar. The plates were incubated at 28°C for 5 days and then all cream-coloured colonies were counted and recorded as CFU/ml.

Statistical analysis

All the data were analyzed using SPSS version 23 (IBM-SPSS version-23) and Pearson correlation matrix for correlation between each physical and bacteriological parameter in a two-tailed significant test at both P value of 0.01 and 0.05. Descriptive statistics such as mean, standard deviation, minimum and maximum values were also computed.

RESULTS AND DISCUSSION

Physical parameter analysis

The physico-chemical parameters investigated were temperature, electrical conductivity, total dissolved solids, residual chlorine and pH as presented (Tables 1, 2, 3 and 4). The mean temperature of the water samples from both treatment plants was 21°C (Table 3 and 4). Although the standard temperature range was above 15°C set by WHO (2017) which was supposed to be ideal for the growth and activity of microorganisms, taste, odor and colour of water, and decrease treatment efficiency (Mulamattathil, 2015; Kawa *et al*., 2016). It is not uncommon to find higher water temperature in the tropics without significant effect on water quality (Desta Kassa, 2009; Solomon Tilahun, 2011). The other physical parameter, pH, was in the range of 6.6–8.1 (Table 1 and 2) with mean value 7.2 (Table 3 and 4). All of them were within the standard limit (6.5–8.5) set by WHO (2017) and Ethiopian Standards Agency (ESA) (2013). The electrical conductivity (EC) of samples in this study was in the range of 178–394 µS/cm from Legedadi treatment plant and 214–296 µS/cm from Gefersa treatment plant (Table 1 and 2).

The EC value in drinking water up to the range of 400 µS/cm is suitable for human consumption and other domestic purposes whereas higher values may cause corrosion of pipe material and reduction of drinking water quality (Pindi *et al*., 2013). However, the data showed that the water quality was good regarding EC. Similarly, TDS was in the range of 101–213 and 106–209 mg/l in Legedadi and Gefersa treatment plants, respectively and the values were much lower than the recommended range (1000 mg/l) set by WHO (2017), indicating there may not be serious problem of hardness and alkalinity across the drinking water distribution system.

The residual chlorine of the water samples was in the range of 0.2–0.7 mg/l (Table 1 and 2). The highest residual chlorine (0.7 mg/l) was recorded from finished water sample sites of Gefersa treatment plants (GF) (Table 2) which exceeded the free residual chlorine range (0.2–0.5 mg/l) recommended by WHO (2017). This highest range of residual chlorine might be because of slow chlorine decay due to intermittent water supply and low water pressure.

Table 1. Physico-chemical parameters of water samples from Legedadi treatment plant and sites along distribution systems.

Sample codes	**Site**	**RCl (mg/l)**	**Temp (°C)**	**EC (μs/cm)**	**TDS (mg/)**	**pH**
LS	Legedadi TP	0.0	20	276	112	6.9
LF	Legedadi TP	0.6	20	241	121	7.4
LR1	Kotebe	0.5	20	285	145	6.8
LT1	Kotebe	0.6	20	394	114	7.8
LT2	Gerji	0.5	20	278	201	7.0
LS1	Bole	0.2	21	291	142	6.8
LS2	Kazanchis	0.3	22	234	119	7.4
LR2	Jan Meda	0.4	20	178	108	7.7
LS3	Sidist kilo	0.2	22	280	140	7.7
LR3	Entoto road	0.5	20	180	121	7.9
LT3	Kazanchis	0.4	22	219	105	7.3
LS4	Piazza	0.4	21	180	101	6.7
LR4	Semen-Hotel	0.5	21	221	113	6.7
LT4	Chilot	0.4	22	220	123	7.0
LS5	Semen hotel	0.3	22	220	213	7.0
LT5	Kechene	0.3	22	181	102	7.3
LT6	Piazza	0.4	21	264	125	7.9
LR5	Dil Ber	0.4	20	296	128	7.0

LS (L= Legedadi, S= source water), LF (f=Legedadi finished water), LR1, LR2, LR3, LR4 and LR5= Legedadi reservoir sample from 5 sites), LT1, LT2, LT3, LT4, LT5 and LT6=Legedadi household tap water samples from 6 sites), LS1, LS2, LS3, LS4 and LS5= Legedadi household storage tanker samples from 5 sites)

Table 2. Physico-chemical parameters of water samples from Gefersa treatment plant and sites along distribution systems.

Sample codes	Site	RCl (mg/l)	Temp (°C)	EC (μs/cm)	TDS (mg/L)	pH
GS	Gefersa TP	0.0	21	286	124	6.6
GF	Gefersa TP	0.7	21	239	120	7.6
GS1	Kolfe	0.3	21	294	209	7.4
GR1	Ras Hailu	0.5	20	220	121	8.0
GT1	Kolfe	0.5	21	275	127	7.1
GR2	Paulose	0.5	21	241	120	7.0
GS2	Bus Station	0.4	21	256	127	6.7
GT2	Abnet	0.5	22	241	123	8.1
GS3	Rufael	0.4	20	236	118	6.6
GS4	Abnet	0.3	22	231	116	8.1
GS5	Ras Hailu	0.3	20	240	110	7.9
GT3	T/Haimanot	0.4	22	231	125	6.9
GS6	T/Haimanot	0.4	22	248	123	6.7
GT4	T/Anbessa	0.4	21	277	118	7.0
GS7	T/Anbessa	0.3	21	296	113	6.6
GS8	Chew Berenda	0.4	21	214	106	7.5

To ensure that treated drinking water is adequately protected from risk of harmful microbial recontamination, WHO recommends minimum residual chlorine of 0.2 mg/l that must be maintained and detected in drinking water supply systems and at the point of consumer delivery. Maintaining sufficient disinfectant concentration alone (0.3 to 0.7 mg/l (Gefersa treatment plant) (Table 2) and 0.2 to 0.6 mg/l at samples from Legedadi treatment plant (Table 1) in drinking water after treatment could not result in either elimination of microbes or suppression of their growth as shown in Fig. 1 and 2. But the residual chlorine concentration after point of disinfectant addition (treatment sites), that is, GF (0.7 mg/l) and LF (0.6 mg/l) of both treatment plants, decreased along the distribution lines with respect to distance of sample sites. Although 98% of sample sites had residual chlorine concentration within recommended range (0.2–0.5 mg/l), reservoirs, tap water and storage tanker samples of household sites in general showed decreased residual chlorine concentration compared to finished water sample sites of both treatment plants.

Similar to this study, Jia and his co-workers reported decreased residual chlorine along different sites of drinking water transportation pipeline (Jia *et al*., 2015). In contrast to this study, there was a wide range and a little bit higher residual chlorine (0.1–1.99 mg/l) maintained in household tap water samples in a study conducted at Bahir Dar City (Milkiyas Tabor *et al*., 2011). The residual chlorine concentration was below the maximum concentration (0.5 mg/l of Cl_2) recommended by WHO at the majority of the samples (75% of samples of Gefersa and 61% of sample sites getting water from Legedadi treatment plant).

Bacteriological parameter analysis

Total and fecal coliforms

Coliform bacteria (both total and fecal coliforms) were detected from all sampling sites which received treated water from both Legedadi and Gefersa treatment plants (Fig. 2 and 3). The total coliform (TC) count was in the range of 3–299 CFU/100 ml and fecal coliform (FC) count was between 2 and 36 CFU/100 ml) across all sampling sites. The highest TC (299 CFU/100 ml) and FC (36 CFU/100 ml) were recorded from source water (LS) and (GS) of Legedadi and Gefersa treatment plants, respectively. The lowest TC (3 CFU/100 ml) and FC (2 CFU/100 ml) counts were recorded from household tap water from LT1 (household tap water) sample location which received water from Legedadi treatment plant.

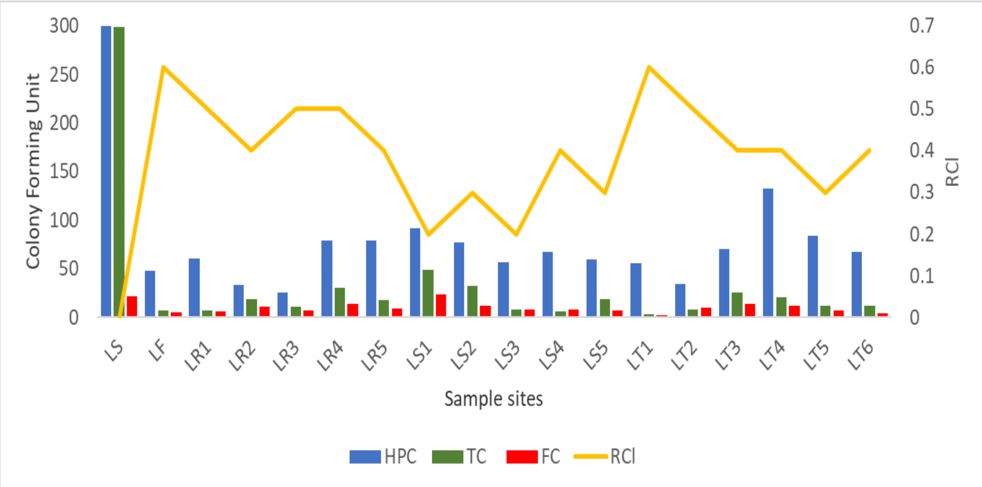


Fig. 2. Bar graph showing concentration of each indicator organism and the impact of residual chlorine on bacterial existence across sampling points that received water from Legedadi treatment plant.

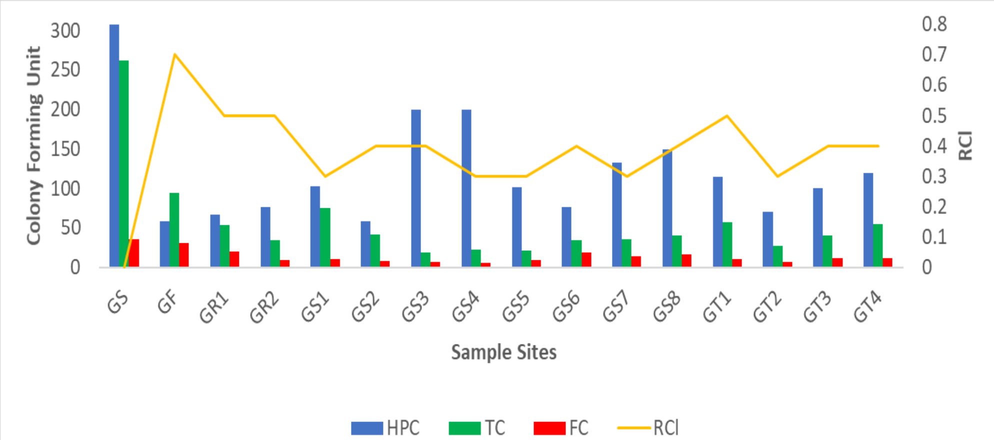


Fig. 3. Bar graph showing concentration of each indicator organism and the impact of residual chlorine on bacterial existence across sampling points that received water from Gefersa treatment plant.

Despite the presence of sufficient residual chlorine for effective disinfection (0.5 mg/l) at each sample location throughout distribution system, coliform organisms were detected from all sampling sites across the distribution systems. At all sampling sites in this study, TC and FC were far below the standard drinking water quality limit set by WHO (0 CFU/100 ml). Similarly, research outputs also showed high coliform (TC) count (up to 100 CFU/100 ml) from treated tap water stored in household storage tankers.

Moreover, household storage tankers sites had high densities of coliforms in the range of 6–49 CFU/100 ml of TC, 7–24 CFU/100 ml of FC and 57–92 CFU/ ml of HPC of compared to tap water samples in the range of 3–26 CFU/100 ml of TC, 2–14 CFU/100 ml of FC and 34–132 CFU/ml of HPC in samples of Legedadi treatment plant whereas household tanker water samples had a range of 19–75 CFU/100 ml of TC, 6–16 CFU/100 ml of FC and 59–149 CFU/ml of HPC compared to tap water sample sites with range from 27–55 CFU/100 ml of TC, 7–12 CFU/100 ml of FC and 71–115 CFU/ml of HPC in Gefersa treatment plant samples (Table 3 and 4).

Table 3. The descriptive statistical results of physico-chemical and bacteriological parameters of samples receiving water from Legedadi treatment plant (n=18).

Parameter	**Descriptive result**				**Acceptable limits**	
	Min	**Max**	**Mean**	**Std. Deviation**	**WHO**	**ENS (Ethiopian National Standard)**
HPC (CFU/ml)	26	300	79	60.3	500 CFU/ml	500 CFU/ml
TC (CFU/100ml)	3	299	32.6	67.5	0 CFU/100 ml	0 CFU/100 ml
FC (CFU/100ml)	2	24	10.1	5.7	0 CFU/100 ml	0 CFU/100 ml
RCl (mg/l)	0	0.6	0.3	0.15	0.2–4 mg/l	0.2–4 mg/l
Temp (°C)	20	22	20.9	.09		
EC (µs/cm)	178	394	246.6	55.2	400 µs/cm	400 µs/cm
TDS (mg/l)	101	213	129.6	31.0	1000 mg/l	1000 mg/l
pH	6.7	7.9	7.2	0.4	6.5–8.5	6.5–8.5

Table 4. The descriptive statistical results of physico-chemical and bacteriological parameters of samples receiving water from Gefersa treatment plant (n=14).

Parameter	**Descriptive result**				**Acceptable limits**	
	Min	**Max**	**Mean**	**Std. Deviation**	**WHO**	**ENS (Ethiopian National Standard)**
HPC (CFU/ml)	58	308	121.1	66.7	500 CFU/ml	500 CFU/ml
TC (CFU/100ml)	19	262	57.3	58.2	0 CFU/100 ml	0 CFU/100 ml
FC (CFU/100ml)	6	36	14.2	8.6	0 CFU/100 ml	0 CFU/100 ml
RCl (mg/l)	0	0.7	0.38	0.15	0.2–4 mg/l	0.2–4 mg/l
Temp (°C)	20	22	21.1	0.7		
EC (µs/cm)	214	296	251.6	26.1	400 µs/cm	400 µs/cm
TDS (mg/l)	106	209	125	23.2	1000 mg/l	1000 mg/l
pH	6.6	8.1	7.2	0.6	6.5–8.5	6.5–8.5

Descriptive results are for source water, finished water, reservoir, household storage tanker and tap water samples

Other studies also showed coliform contamination of drinking water in pipes distribution systems from Addis Ababa (Dawit Mekonnen, 2015), Wondo genet Campus (Yirdaw Meride and Bamlaku Ayenew, 2016) and Jimma zones (Derara Chalchisa *et al*., 2017) and Southwest Ethiopia (Tadesse Sisay *et al*., 2017), Selamawit Mulugeta (2012) showed that 67% of household tap water samples from Merkato area, in Addis Ababa contained fecal coliforms. Moreover, Gonfa Duressa *et al*. (2018) also showed that total coliforms with a range of 12–120 CFU/100ml were detected at all samples analyzed with residual chlorine concentration of <0.5mg/l. The detection of indicator bacteria of treated water in the distribution lines indicated either depletion of residual chlorine or leakage at certain points of distribution systems. Although organic matter (OM) was not measured in this study, its presence through leakage might be one of the reasons for the ineffectiveness of disinfection and for the rapid growth and presence of coliform in high number at most sample sites (Singh *et al*., 2013). Similarly, Nescerecka *et al*. (2014) indicated that considerable increase in coliform and other biological parameters in drinking water distribution systems is associated with rapid decay of chlorine. In general, the type of source water, organic and inorganic matter present in the water, pipe materials used for distribution, efficiency of treatment process, type and size of household storage tankers also contribute to microbial re-growth in treated drinking water (Ashbolt, 2015; Zaqoot *et al*., 2016).

Heterotrophic bacteria plate count (HPC)

Heterotrophic bacteria plate count (HPC) was analyzed for samples collected from different sites across distribution lines and household point of use sites of both Legedadi and Gefersa treatment plants (Fig. 2 and 3). HPC was in the range of 26–308 CFU/ml and the highest HPC (308 CFU/ml) count was recorded from source water of Gefersa treatment plant (GS); whereas the lowest HPC (26 CFU/ml) count was detected from sample LR3 (reservoir) which received treated water from Legedadi treatment plant. Similarly, HPC greater than 100 CFU/ml was found in different sample sites (Tesfaye Legesse *et al*., 2018). On the other hand, the result was much lower than indicated by Shakya *et al*. (2012) where 95% of 114 sample sites had HPC>0 CFU/100ml in a study of evaluation of physico-chemical and bacteriological parameters in drinking water supplied through distribution systems.

Correlation analysis of physico-chemical parameters with each other and with indicator organisms showed some of the physico-chemical parameters had significant positive correlation with each other as shown in Table 5 and 6. HPC had a significant positive correlation with TC (r = 0.934) at P value of 0.01 (Table 5) and r = 0.599 at P value of 0.05 (Table 6) and FC (r = 0.614) whereas a significant negative correlation with RCl with r = -0.620 (Table 5) and r = -0.792 (Table 6), both at P value of 0.01. There was negative correlation between TC and temperature (r = -0.183 and r = -0.044), FC and temperature (r= -0.070), TC had negative correlation with TDS (r = - 0. 144) as well as the negative correlation value of F with TDS was (r = -0.076 and r = -0.067) and FC had significant negative correlation with pH (r = -0.500). On the other hand, TC and FC had a significant positive correlation with each other (r = 0.643 and r = 0.811) and significant negative correlation with RCl at a value of r (r = - 0.638 and r = -0.614), respectively. The positive Pearson correlation between EC and TDS were r = 0.198 and r = 0.477, respectively.

Table 5. Correlation matrix of r-values of physico-chemical parameters and indicator bacterial counts of sample sites of Legedadi treatment plant (To is temperature).

	HPC	**TC**	**FC**	**RCl**	**To**	**EC**	**TDS**	**pH**
HPC	1							
TC	0.934**	1						
FC	0.614**	0.643**	1					
RCl	-0.620**	-0.638**	-0.614**	1				
To	0.001	-0.183	0.094	-0.222	1			
EC	0.130	0.112	-0.056	0.114	-0.333	1		
TDS	-0.214	-0.144	-0.076	0.064	0.024	0.198	1	
pH	-0.364	-0.256	-0.500*	0.167	-0.050	0.056	-0.207	1

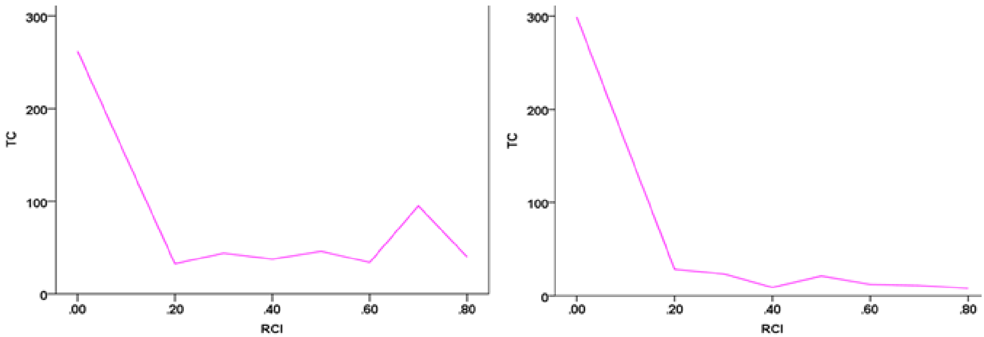
Table 6. Correlation matrix of r-values of physico-chemical parameters and indicator bacterial counts of sample sites of Gefersa treatment plant (To is temperature).

	HPC	**TC**	**FC**	**RCl**	**To**	**EC**	**TDS**	**PH**
HPC	1							
TC	0.599*	1						
FC	0.292	0.811**	1					
RCl	-0.792**	-0.486	-0.113	1				
To	-0.063	-0.044	-0.070	-0.056	1			
EC	0.236	0.425	0.137	-0.396	0.013	1		
TDS	-0.110	0.148	-0.067	-0.110	0.055	0.477	1	
pH	-0.263	-0.265	-0.159	0.228	0.011	-0.484	-0.002	1

* Correlation is significant at the 0.05 level (2-tailed), **. Correlation is significant at the 0.01 level (2-tailed)

In classical water quality assessment techniques, coliform groups (TC and FC) and heterotrophic bacteria (HPC) are surrogate drinking water quality indicator organisms and they are used for the assessment of microbiological safety of water and the presence of water-borne pathogens (Mulamattathil *et al*., 2015). The significant positive correlation of TC and FC showed increasing coliform bacteria directly corresponds with increasing microbes of fecal origin which in turn indicated contamination of drinking water with wastes of sewage and other domestic sources. Moreover, submerged biofilms in water are the main sources of coliforms in drinking water distribution systems. Increasing HPC in drinking water distribution systems resulted with high number of coliforms and other pathogenic microorganisms (Karikari and Ampofo, 2013).

There was a negative relationship between residual chlorine and coliform bacteria in this study. One of the causative agents of high density of bacteria in drinking water distribution systems is low amount of residual chlorine. The relationship between indicator bacteria and residual chlorine is illustrated clearly in Fig. 2 and 3 as well as Fig. 4A and B, C and D and E and F. As the residual chlorine concentration gets higher, the number of indicator bacteria decreased and at low residual chlorine concentration, high number of bacteria counts was observed. This literally suggested efficiency of disinfection should basically be effective in eliminating or reducing the number of bacteria. As observed from Fig. 2, 3 and Table 5, 6 residual chlorine couldn’t eliminate bacteria and considerable amount was detected and this may be due to survival of bacteria against disinfection and formation of biofilms inside the pipe systems.



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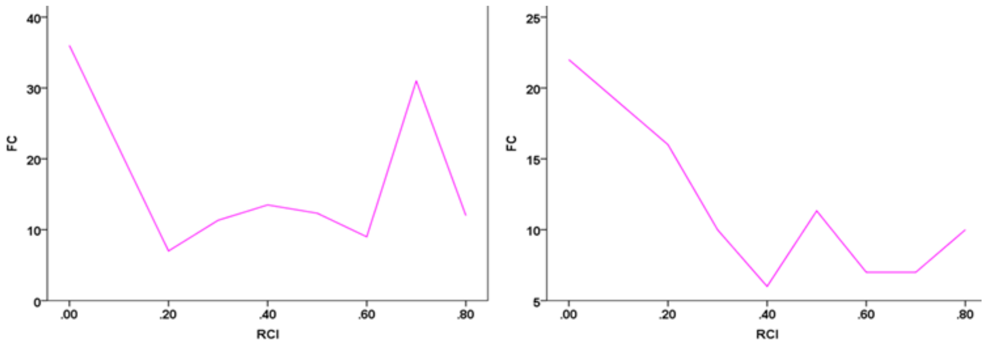

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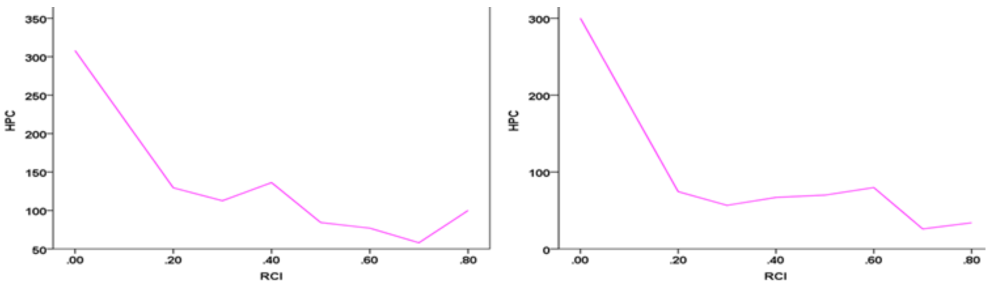

E F

Fig. 4. The graphical illustration of the relationship of Total coliforms and Residual chlorine (A and B), Fecal Coliforms with RCl (C and D) and HPC with RCl (E and F). A, C and E are figure of samples from Gefersa treatment plant whereas B, D and F are that of Legedadi treatment plant site.

CONCLUSION

The presence of considerable number of bacteria starting from source water of the two treatment plants (Gefersa and Legedadi) across all the sampling location of the distribution systems is an indicator of declining of drinking water quality. In this study, although physico-chemical parameters amount of residual chlorine that should be maintained in drinking water were within the standard limit of WHO and national standards of Ethiopia set for treated drinking water. Coliform organisms were counted in significant numbers which confirms contamination via leakage through broken pipes, improper repair or inefficient disinfection due to the presence of organic matter inside distribution networks. This normally leads to health risks which might be due to the presence of pathogenic and opportunistic pathogenic bacteria even at sample sites very close to the treatment plants. The presence of such significant number of indicator bacteria may be due to regrowth and survival of these bacterial groups against treatment process. It is highly recommended to undertake regular bacteriological assessment with respect to residual chlorine concentration, effectiveness of disinfection and other treatment processes and surveillance of possible contamination sources following the distribution lines.

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REFERENCES

Amsalu Mekonnen, Kemal Jemal, Gebru M.Woldearegay and Kassu Desta (2020). Quality and safety of municipal drinking water in Addis Ababa City, Ethiopia. *Environ. Health Prev. Med*. **25**. https://doi.org/10.1186/s12199-020-00847-8

Ashbolt, N.J. (2015). Microbial contamination of drinking water and human health from community water systems. *Curr. Environ. Health. Rep*. **2**(1): 95–106.

CSA (Central Statistics Agency of Ethiopia) (2014). Population projection of Ethiopia for all regions at wereda level from 2014–2017.

Dawit Mekonnen (2015). **The Effect of Distribution Systems on Household Drinking Water Quality in Addis Ababa, Ethiopia, and Christchurch, New Zealand**. Master's Thesis, University of Canterbury, New Zealand.

Derara Chalchisa, Moa Megersa and Abebe Beyene (2017). Assessment of the quality of drinking water in storage tanks and its implication on the safety of urban water supply in developing countries. *Environ. Syst. Res.* **6**(12). https://doi.org/10.1186/s40068-017-0089-2

Desta Kassa (2009). **Physico-Chemical and Bacteriological Quality Assessment of Drinking Water from Source to Households Distribution Point in Debre Zeit Town, Ethiopia**. Master's Thesis, Addis Ababa University, Addis Ababa.

ESA (Ethiopian Standards Agency) (2013). **Drinking Water Specifications. Compulsory Ethiopian Standards, CE58.** First edition. Ethiopian Standards Agency. Addis Ababa.

Gonfa Duressa, Fassil Assefa and Mulissa Jida (2018). Assessment of bacteriological and physic-chemical quality of drinking water from source to household tap connection in Nekemte, Oromia, Ethiopia. *J. Environ. Public Health*: 1–8. https://doi.org/10.1155/2019/2129792

Jia, S., Shi, P., Hu, Q., Li, B., Zhang, T. and Zhang, X.-X. (2015). Bacterial community shift drives antibiotic resistance promotion during drinking water chlorination. *Environ. Sci. Technol.* **49**(20): 12271–12279.

Karikari, A.Y. and Ampofo, J.A. (2013). Chlorine treatment effectiveness and physico-chemical and bacteriological characteristics of treated water supplies in distribution networks of Accra-Tema Metropolis, Ghana. *Appl. Water Sci.* **3**(2): 535–543.

Kawa, Y.K., Kaisam, J.P., Moiwo, J. and Kabia, V. (2016). Physical, chemical and bacterial analysis of drinking water: Kakua Chiefdom, BO district, Sierra Leone. *Int. J. Water Resour. Environ. Eng.* **8**(1): 11–23.

Metadel Adane, Bezatu Mengistie, Girmay Medhin, Helmut Kloos and Worku Mulat (2017). Piped water supply interruptions and acute diarrhea among under-five children in Addis Ababa slums, Ethiopia: A matched case-control study. *PLoS ONE*. **12**(7): e0181516.

Milkiyas Tabor, Mulugeta Kibret and Bayeh Abera (2011). Bacteriological and physic-chemical quality of drinking water and hygiene-sanitation practices of the consumers in Bahir Dar city, Ethiopia. *Ethiop. J. Health. Sci.* **21**(1): 1–8.

Mulamattathil, S.G., Bezuidenhout, C. and Mbewe, M. (2015). Analysis of physico-chemical and bacteriological quality of drinking water in Mafikeng, South Africa. *J. Water Health* **13**(4): 1143–1152.

Nescerecka, A., Rubulis, J., Vital, M., Juhna, T. and Hammes, F. (2014). Biological instability in a chlorinated drinking water distribution network. *PLoS One* **9**(5):e96354.

Pindi, P.K., Yadav, P.R. and Kodaparthi, A. (2013). Bacteriological and physico-chemical quality of main drinking water sources. *Pol. J. Environ. Stud.* **22**(3): 825–830.

Qaiser, S., Hashmi, I. and Nasir, H. (2014). Chlorination at treatment plant and drinking water quality: A case study of different sectors of Islamabad, Pakistan. *Arab. J. Sci. Eng.* **39**(7): 5665–5675.

Selamawit Mulugeta (2012). **Assessment of Drinking Water Quality in Mercato.** M.Sc. Thesis, Addis Ababa University, Addis Ababa.

Shakya, P., Joshi, T.P., Joshi, D.R. and Bhatta, D.R. (2012). Evaluation of physic-chemical and microbiological parameters of drinking water supplied from distribution systems of Kathmandu Municipality. *Nepal J. Sci. Technol.* **13**(2): 179–184.

Singh, U., Lutchmanariyan, R., Wright, J., Knight, S., Jackson, S., Langmark, J., Vosloo, D. and Rodda, N. (2013). Microbial quality of drinking water from ground tanks and tankers at source and point-of-use in eThekwini Municipality, South Africa, and its relationship to health outcomes. *Water SA* **39**(5): 663–673.

Solomon Abera, Ahmed Zeyinudin, Biruktawit Kebede, Amare Deribew, Solomon Ali and

Endalew Zemene (2011). Bacteriological analysis of drinking water sources. *Afr. J. Microbiol. Res.* **5**(18): 2638–2641.

Solomon Tilahun (2011). **Assessment of Selected Bacteriological and Physico-chemical Characteristics of Sululta Town Drinking Water from Source to Pipe Water**. Addis Ababa University, Addis Ababa.

Tadesse Sisay, Abebe Beyene and Esayas Alemayehu (2017). Assessment of drinking water quality and treatment plant efficiency in Southwest Ethiopia. *J. Environ. Sci. Pollut. Res*. **3**(3): 208–212.

Tesfaye Legesse, Frehiwot Abera, Waktole Gobena, Samson Girma, Redwan Muzeyin, Almaz Gonfa, Dejenie Shiferaw and Kassu Desta (2018). Virological and bacteriological quality of drinking water in Ethiopia. *Int. J. Infect. Dis.* **8**(73):1–6.

WHO (World Health Organization) (2017). **Guidelines for Drinking Water Quality**. Fourth edition incorporating the first addendum. World Health Organization, Geneva.

WHO (World Health Organization) and UNICEF (2017). **Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG Baselines**. World Health Organization (WHO) and the United Nations Children's Fund (UNICEF), Geneva.

Yirdaw Meride and Bamlaku Ayenew (2016). Drinking water quality assessment and its effects on residents health in Wondo Genet campus, Ethiopia. *Environ. Syst. Res*. **5**(1):1–7.

Zaqoot, H., Hamada, M. and El-Tabash, A.M. (2016). Investigation of drinking water quality in the kindergartens of Gaza Strip Governorates. *J. Tethys* **4**(2): 88–99.

Zin, T., Mudin, K., Myint, T., Naing, D., Sein, T. and Shamsul, B. (2013). Influencing factors for household water quality improvement in reducing diarrhoea in resource-limited areas. *WHO South-East Asia J. Public Health* **2**(1): 6–11.