Water Safety Practices Along the Water Service Chain in Addis Ababa: A Cross-Sectional Study in a Cosmopolitan City

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ABSTRACT: This study investigated water safety practices and risk levels along Addis Ababa's water supply service chain. The data came from 23 random woredas, 384 random households, 115 microbiological water quality tests, and diagnostic inspections from source to point of use. Findings from this study indicate that the surface water sources (53%) and the water source catchments (62%) are characterized by very high-risk and high risk contamination levels respectively. Conversely, the water treatment process (5%) and temporary reservoir (20%) indicates a low risk level. Whereas the water distribution system (40%), water source boreholes (44%), and Household level (29%) water safety practices are identified as medium risk levels. The microbial analysis of the drinking water at the source and point of use indicated low (<11 CFU/100 ml) to high levels (>100 CFU/100 ml) of risk with significant levels of contamination at the household level. Moreover, the household-level water safety practice assessment revealed intermediate to very high levels of risks. The Chi^2 test shows that water supply type is significantly associated with occupation($X2(12,384) = 23.44$, $P < .05$) and education($X2(8,384) = 15.4$, $P < .05$). Multinomial regression analysis also showed better occupation is associated with increased access to safe bottled water compared to safe piped water on premises. It can be concluded that the water safety practice encountered low to very high levels of risk of contamination at different components along the water supply service chain and the household level. This study suggests ways to improve Addis Ababa residents' health and well-being through water safety interventions. These include safeguarding water sources, supporting local safe water businesses, providing household water treatment, and handling options, and addressing the barriers and incentives for adopting safe water practices.

KEYWORDS: Drinking water, water safety, water supply, water treatment

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Introduction

Water is essential for human health, well-being, and development, but many people worldwide lack access to safe drinking water. According to the WHO/UNICEF Joint Monitoring Program 2021 update and SDG baselines, 2 billion people do not have safely managed water services at home, exposing them to various waterborne diseases that can cause illness, disability, and death.[1] Water safety practices are the actions and measures water providers and users take to manage the risks of drinking water from the source to the point of use.[2] This method covers all the drinking water delivery stages, such as water catchment, storage, treatment, and distribution. It aims to ensure that drinking water is safe and meets quality standards.

Ensuring water safety along the supply chain is a critical measure that helps prevent water-related disease and provides access to safe drinking, as water is a fundamental human right. According to UNICEF,[2] in 2020, 5.8 billion people used safely managed drinking water services, but 2 billion people still lacked even a basic level of service. The World Health Organization[3] states that microbial contamination of drinking water due to fecal pollutants poses the most significant risk to safe drinking water and is estimated to cause 485 000 diarrheal deaths yearly.

Ethiopia faces many challenges in providing safe water services to its population, such as water scarcity, pollution, infrastructure gaps, governance issues, and climate change. According to the latest data from the Joint Monitoring Program, only 42% of the population had access to essential water services in 2017.[4] A study conducted on the impacts of WASH coverage and potential contribution to the decline in diarrhea and stunting in Ethiopia stated that[4] only 50% of rural and urban households in Ethiopia have access to essential water services (ie, water from an improved source, with collection time not more than 30 minutes round trip), and 6% have access to basic sanitation facilities (ie, an improved facility ie, not shared).

A study on the bacteriological and parasitological quality and safety status of all Addis Ababa municipal drinking water sources during the rainy season found that some samples were contaminated with coliforms, indicating fecal pollution. It recommended continuous screening and treatment of water sources to prevent waterborne diseases.[5]

However, water users and providers along the water service chain lack awareness and understanding of unsafe water's potential hazards and risks.[6]

Many communities with poor water and sanitation conditions suffer from diseases caused by microorganisms in drinking water.[7] Unsafe drinking water and sanitation can also transmit infectious diseases such as cholera, diarrhea, dysentery, typhoid, and Guinea worm infection.[8] However, the water safety measures along the water service chain, which covers drinking water's source, storage, treatment, and distribution, are not well-known in Ethiopia, especially in Addis Ababa. The city faces many challenges in providing reliable water and sanitation services, and the hygiene practices are also poor. A 2008 assessment showed that many households and slum dwellers lacked toilet facilities, shared toilets with too many families, did not collect their garbage, and did not have adequate sanitation facilities.[9] Moreover, rapid industrialization, population growth, lack of sewerage networks, and poor living conditions can worsen the quality of surface and groundwater in the city. Therefore, this study aims to assess the water safety measures along the water service chain in Addis Ababa and provide recommendations for improving water quality and safety.

Materials and Methods

Description of the study area

This study was conducted in Addis Ababa, which has about 6 million residents.[10] The city covers an area of 54 km² and has an altitude ranging from 2000 to 2800 m. It is the seat of federal and regional governments and is surrounded by the Oromia National Regional State. The city is divided into 10 sub-cities and 116 woredas.[10]

The city is growing fast due to urbanization and massive infrastructure development. Addis Ababa is home to over 2000 industries, ranging from potable water, cement, textile, beverage and alcohol, tobacco, leather, tannery, plastic, and food factories. The metropole is the country's industrial, cultural, administrative, commercial, and modern hub.[11] It is also one of the central hubs in Africa, with its many international organizations and institutions. It is home to the African Union, United Nations Economic Commission for Africa, and over a 100 embassies. It is said to be Africa's diplomatic capital and a beacon of humanitarian progress on the African continent. Only 64% of the solid waste produced is correctly disposed of; about 74% of the residents use pit latrines, 7% use flush toilets, and 17% use open defecation.[12]

Research design and population selection

This research aimed to assess the existing water safety practices along all components of the water service provision chain in Addis Ababa, and it was conducted in a participant and process-oriented manner. The research involved collaboration with all stakeholders involved in the water service provision chain in Addis Ababa, ensuring a comprehensive understanding of the entire system. The study involved measuring and analyzing the critical water safety measures at every stage of the water service provision chain, from the water source to its delivery to the end user. The research aimed to identify existing gaps in the application of water safety measures along the water service chain and its implications for human health. The study involved 2 approaches: cross-sectional design and microbiological analysis. The cross-sectional study design involved qualitative and quantitative assessment methods through primary data collection from the water source to the point of use.

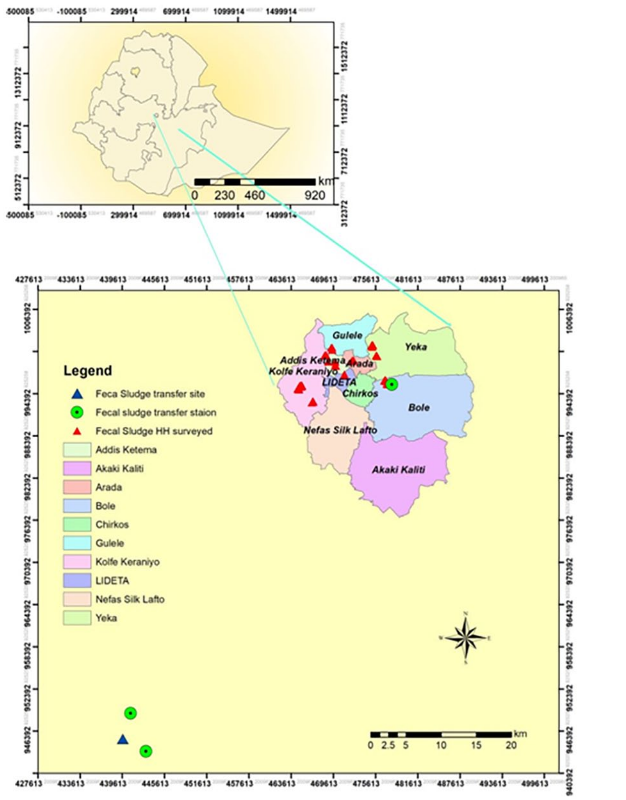

Figure 1. Maps of study sites showing water quality sampling points.

For the cross-sectional study, all the city's 4 primary drinking water sources were included: Gefersa, Legedadi, Dire, and Akaki well fields, with all their service chain components from source to the point of use. Purposively selected water service provision actors (The water utility and water users) who are working and using across all the components of the water service chain from the water source to the point of use were selected for critical informant interviews (KII). The key informants were the personnel responsible for the water source, the treatment facility, temporary reservoirs, and the distribution system, who provided primary information and showed the facilities and processes.

Microbiological analysis was used to measure the microbial loads (*E. coli* CFU/100) in water samples taken from the sources, reservoirs, distribution system, and point use (in the households). The data were generated through microbiological analysis from samples collected from sampled households along the service chain components (at the water source, catchment, treatment process, reservoir, and distribution systems). Households along the full package of the water service chain were randomly selected for the households' survey. The below map illustrates the areas where water samples have been collected for water quality analysis (Figure 1).

Sample size determination and sampling techniques

The sample size for the household survey

The sample size was computed by taking a 95% confidence level ($Z = 1.96$), 50% proportion, 5% margin of error (d), and 5% non-response rate on one using the single population proportion formula as follows: $n = \frac{Z^2 P(1-P)}{d^2}$

Where n = the required sample size

p = the average proportion of different settings

Z = the critical value at 95% confidence level = 1.96

d = precision (margin of error) = 5%

The sample proportion (P) is selected by taking 50% as we couldn't find previous studies related to water safety in Addis Ababa, and we don't have time to carry out a pilot study to determine "P." With this consideration, it is safer to assume the worst-case scenario, and the proportion is likely to be 50%. This helped to allow for having the largest possible sample size.

Accordingly, the calculated sample size was 384. Based on the above equation, the final sample size required for the household survey, considering a 5% non-response rate, was 384 + 19 = 403.

Sample size for drinking water microbiological analysis

Due to our financial constraints, a total of 115 water samples were collected. Of these, 101 water samples were collected from households, and 14 water samples were collected from water infrastructures across 23 woredas with very close consultation with the City Water and Sewerage Authority.

The water infrastructures were purposively selected, considering their service coverage, as most of the city's population receives water services from these selected infrastructures. As a result, 4 water sources, 4 water reservoirs, and 6 water distribution lines were used for water quality testing.

Sampling Technique and Sampling Procedure

The study subjects and areas under the water service chain were selected from the total number of Addis Ababa city administration Districts/ woredas using simple random and cluster sampling methods.

However, the primary sampling units (Woredas/Districts) were selected using simple random and purposive sampling techniques. Accordingly, 20% (116) of the total woredas, 23 Districts, were chosen for the household survey.

Following the selection of the primary sampling unit (Districts), the secondary sampling unit (Ketenas/ Neighborhoods) was considered clusters with the presumption of homogeneity among them concerning water safety practices. Neighborhoods within the randomly selected woredas were included based on the Probability Proportion to sampling from each study sampled woredas.

The sampling frame was constructed by obtaining the list of Neighborhoods with their household size from the sample woredas. Secondly, Neighborhoods were randomly selected from the sample of 23 woredas. Assuming that one woreda will have an average of 6 Neighborhoods and that those chosen randomly woredas have a total of 138 Neighborhoods, a total of 28 Neighborhoods (20% of the 138 Neighborhoods) were selected.

Then, the number of households in each selected Neighborhoods was determined using Probability Proportional to Size (PPS). In this case, size is defined as the total number of households derived from the population size in sampled Neighborhoods.

Finally, tertiary sampling units (Households) were selected using the spin-the-pen technique to identify the starting point within a sampled Neighborhoods. Spinning a ballpoint pen at the center of the Neighborhood helped the study team randomly choose a direction to follow. Once the starting household had been identified, households that are the water service chain beneficiaries and residing in the sampled Neighborhoods were interviewed/observed, and a water quality sample was collected using a standardized questionnaire until the desired sample size per Neighborhood was achieved.

For microbiological analysis (drinking water quality test), water samples were collected from consumers/households and the water infrastructure. Sample collection, transport, and testing were done following the international Standard Methods for the Microbiological testing of water samples.[13] We used suitable containers, labels, preservatives, and temperatures to ensure the quality and integrity of the samples. The samples were collected in 250 ml sterile water-sampling bottles with a few drops of sodium thiosulphate added to neutralize the residual chlorine, then stored in the ice box, and transported to Addis Ababa Water and Sewerage Authority Central Laboratory (AAWSA).

Data collection methods and Tools

We conducted interviews and diagnostic sanitary inspections to explore the experiences of households and service providers regarding safe water handling and delivery. We used checklists to observe safe water management at the point of use, water source, water treatment process, temporary storage, and distribution systems. We also interviewed water users and utility staff using semi-structured questions.

The data were collected using a structured questionnaire adapted and customized to assess each water supply service chain components. The structured assessment tools were adopted from the WHO Water Safety Plan Manual first and second editions and the Ethiopian Climate Resilient Water Safety Plan guidelines for Ethiopia Urban Utility Managed Piped Drinking Water Supplies. Then, the tools were designed in English and translated and administered into the city's common language, "Amharic."[14,15]

Experienced data collectors with at least a Bachler of Science degree in environmental health were selected and trained for 2 days to conduct the household survey. Field supervisors with an MSC degree in environmental health provided supportive supervision to data collectors during actual data collection. For qualitative data collection, 4 data collectors with an MSC degree in environmental health were assigned to collect qualitative data across the water service chain.

Water quality analysis

The bacteriological water quality analysis was done within 6 hours of sample collection. The membrane filtration method was used to analyze E. coli, following the standard method for examining water and wastewater.[16] The microbial quality of the drinking water was evaluated by microbiological analysis of the load of *Escherichia coli (E. coli)* in the water samples.

Data analysis

Data analysis was carried out by using SPSS version 26 software. Frequencies and proportions were used for data presentation. Water safety risk practices were categorized based on the Guidelines for drinking-water quality: Fourth edition incorporating the first and second addenda,[8] which was categorized based on the risk score as Low risk (0-2), Medium risk (3-5), High risk (6-8), and Very high risk (9-10). The risk levels of water safety practices at each component of the water supply system were evaluated based on standard scores assigned based on diagnostic sanitary inspection questions.

The chi2-test was used to evaluate the association between sociodemographic factors and risk levels of the water safety practice. Multinomial logistic regression was employed to predict the effects of changes in factors on the risk levels of water safety practices. Factor analysis was used to analyze risk variables of water safety practices using PCA to extract factors and Kaiser Criterion to determine factor levels and varimax for rotation. Loadings close to −1 or 1 indicate that the variable strongly influences the factor. Thematic and content analysis was conducted for the qualitative data collected through interviews and water safety practice observation along all the components of the water service chain.

Ethical considerations

The ethical review board of the Ministry of Education Science and Research affairs directorate and the Ethiopian Water Institute, Addis Ababa University, approved the study. The study objective was communicated to the Addis Ababa Water and Sewerage Authority, who assigned staff to support the study team during data collection in selected woreda administrations. The study participants were informed about the purpose and importance of the study and gave verbal consent. The data collection respected the confidentiality of the information by omitting personal identifiers.

Results and Discussion

Socio-demographic characteristics of the study participants

Three hundred eighty-four respondents participated in the study with a 4.7% non-response rate. The proportion of the significant socio-demographic characteristics of the study population is presented in Table 1. The respondents were mothers (39%), daughters/sons (26%), fathers (23%), house cleaners (10%), and others (13%). Most house heads were males (238, 68%), married (223, 58%). Most respondents (364, 95%) have low to moderate incomes.

Table 1. Socio-demographic characteristics of study participants.

CHARACTERISTICS	FREQUENCY (%)
Gender of the house head	
Female	146 (38)
Male	238 (61)
Category of respondents	
Daughter/son	98 (26)
Father	51 (23)
Housemaid	37 (10)
Mother	148 (39)
Others	50 (13)
Education	
Can't read and write	38 (9.4)
Primary education (1-8)	88 (23)
Higher diploma (diploma to Masters)	92 (24)
Read and write only	57 (15)
Secondary (9-12)	29 (11)
Marital status	
Married	223 (58)
Separated	20 (5)
Single	119 (31)
Widow	22 (6)
Income	
High	20 (5)
Intermediate	198 (52)
Poor	166 (43)
Occupation	
Retired	8 (2)
No job	11 (3)
Business	41 (11)
Daily laborer	14 (4)
Housemaid	105 (27)
Housewife	38 (10)
Student	94 (25)
Private employee	52 (14)
Government employee	

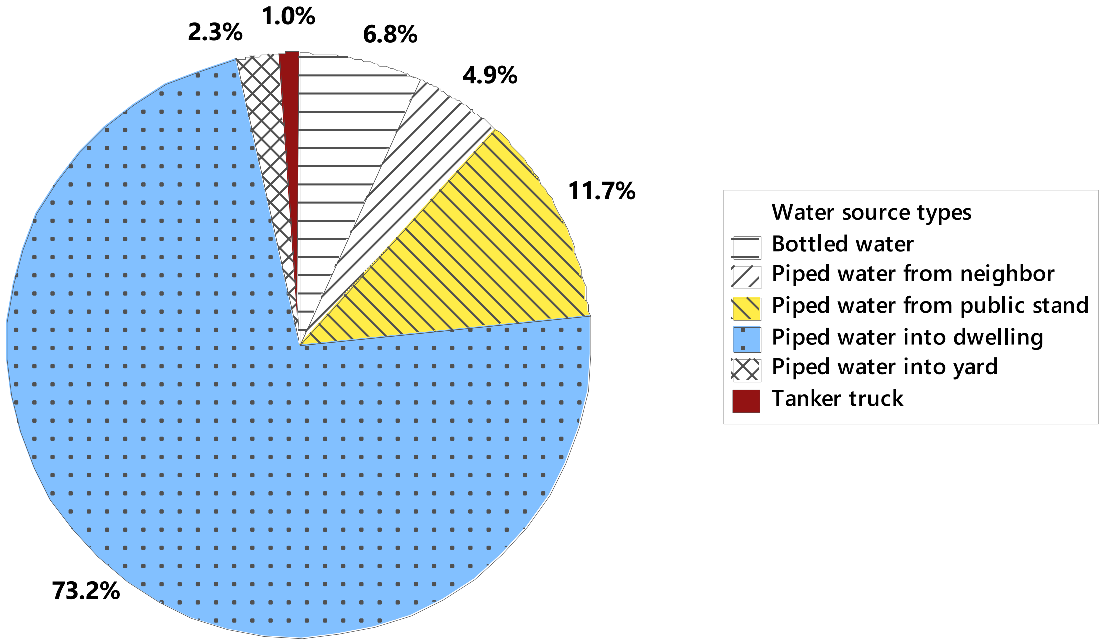

Figure 2. The proportion of water supply types in Addis Ababa.

Access to safe water supply

During the survey, 4 drinking water sources were identified. Most households (354, 92.2%) obtained their drinking water from piped water on the premises.

Considerable numbers of the households (24, 6.2%) had been using piped water from public stands, and a proportion of the residents (6, 1.6%) obtained their drinking water from different sources such as tanker trucks, bottled water, and piped water from neighbors. We found that 99% of the community access improved water supply services (Figure 2).

Although the association between access to safe drinking water and the gender of the household head was not significant (X2(12,384) = 3.5, P = .17), female-headed households had a higher probability (95%) of using improved drinking water than males (90%). There was a significant association between access to safe drinking water and occupation of the household head ($X^2(12,384) = 23.44, P < .05$) with the majority of the private business-engaged respondents, compared to other occupation types installed piped into the dwelling water source. Although the association with income was insignificant, those engaged with private business had higher installed piped water in their dwelling ($X^2(12,384) = 3.2, P = .5$).

Access to safe drinking water was also significantly associated with the educational status of the household head, indicating that all education group respondents had a preference for access to piped water on premises ($X^2(8,384) = 15.4, P < .05$). Multinomial regression analysis of water supply source type and socio-economic variables show that a one-unit increase in educational status is associated with a 0.078 decrease in the relative log odds of access to safe water from piped-on premises compared to access to piped water from a public stand.

Water safety practices and risks from source to consumers

This study finding highlights the risk levels associated with different components of the water supply service chains in Addis Ababa city. The category of water source-surface water demonstrated a very high risk (53%) while boreholes, serving as another water source, fell into the medium risk category (44%). The water source catchment exhibited a high-risk level (62%). Drinking water treatment is at a low risk level (5%) and the water distribution system was classified as medium risk (40%). The temporary reservoir showed a low risk level (20%) and household-level water safety practices were identified as medium risk level (29%). The summary of the water safety risks and scores along the service chain is presented in Table 2.

Water safety practices at the source and catchment. Among the 17 diagnostic assessments of the surface water sources, 53% (9) were identified as water safety practices or risk practices in the source. These risk factors include the presence of livestock and human activity, animal and bird droppings, agricultural activities, significant spills, runoff from roads, and natural events around the sources and in the catchment. In the case of the Akaki-Kality area borehole sources, 4 water safety practices out of 9, namely the presence of livestock, human activity, percolating surface water, and agricultural activity, were identified as risk factors (Table 2).

Diagnostic sanitary observations at the catchment also showed that 8 out of 13 inspection responses indicated the presence of challenges along the water supply service chain. The catchment is free from untreated sewage and industrial wastes, mining, major spills, and landslides. However, during the observation, human-related factors such as using fertilizer,

Table 2. Summary of the risk levels of water safety practices along the water supply chain evaluated by standard risk scores based on sanitary inspection questions (SIQ).

WATER SUPPLY SERVICE CHAIN	SCORE*	%	WHO RISK LEVEL			
			LOW RISK 0-2	MEDIUM RISK 3-5	HIGH RISK 6-8	VERY HIGH RISK 9-10
Water source – surface water	9/17	53				9
Water source – Boreholes	4/9	44		4		
Water source catchment	8/13	62			8	
Drinking water treatment	2/37	5	2			
Water distribution system	4/10	40		4		
Temporary reservoir	1/10	20	2			
Household-level water safety practice	4/14	29		4		

*Score: WHO scores given based on sanitary inspection questions (SIQ). Seventeen surface water SIQ, 9 bore hole SIQ, 13 water source catchment SIQ, 37 drinking water treatment SIQ etc.
The color green to red informs the level of risk from low to very high.

pesticides, and herbicides on the farm, disposal of solid wastes, runoff from roads, animal husbandry, and other water source-related human activities such as bathing, cloth washing, and recreation were evident. Moreover, natural phenomena such as algal blooms, heavy rains, and flooding in the watershed were everyday events indicating that the water source was exposed to the influx of extraneous materials from the catchment. Therefore, according to the WHO Water Safety Plan Manual Second Edition,[17] the catchment attributes a high-risk level (62%) of the water supply service chain (Table 2).

Water safety practices during the treatment process. Thirty-seven specific diagnostic information were collected to assess the treatment process along the drinking water service chain, from which 2 were identified as risk factors for drinking water quality. The risk factors include infrequent filter backwashing and the challenges related to staff risk factors along the water supply chain. This implies that among those potentially risk practices, at a low risk level (5%) were practically risk factors associated with the ineffectiveness of the treatment process.

Water safety practices at the temporary reservoir. Water safety practices at the temporary storage were assessed through a sanitary inspection of the reservoir. Among the 10 sanitary assessment questions, 2 (source of other pollution within 50 m and human excrement on the ground within 10 m of the reservoir) were identified as risk factors. This implies that 80% of the sanitary inspections used to assess the risks of water safety practices at the temporary storage were properly practiced to maintain drinking water quality at household levels. The cleanliness of the inside of the tanker, the presence of cover and fencing, the absence of sewer nearby, the lack of algal growth, the protection to the runoff, and the imperviousness of the reservoir to access by animals do not have any negative attributes to the safety of the drinking water.

Water safety practices at the water distribution system. The risk of practices at the water distribution scheme was examined using 10 sanitary inspection information; among these, 2 water safety risk practices, including illegal or unauthorized connections and poor pipeline repair/installation practices, were identified as a risk factor. Moreover, contaminants drawn into the system due to a combination of low pipeline pressure (eg, intermittent operation), presence of sub-surface contaminants (eg, sewers, drains, garbage pits, pit latrines), breaks or leaks in pipeline and backflow (eg, from consumers' tanks or hose connections) were also observed at the distribution line reservoir. This indicates approximately the water distribution system was classified as medium risk (40%).

The drinking water quality at the point of use depends on the practices in the water supply system components. Any failure in the water safety practices along the water supply chain or in either of the components leads to an increased load of *E. coli* in the drinking water at the point of source, indicating the increased risk of drinking water in the house. The component of the water supply system close to the household affects the drinking water at the point of use. Accordingly, in this study, household-level water safety practices contribute more to the increased *E. coli* level in the drinking water at the point of use.

Water safety practices and risks at the household level/point of use

The relationship between water safety practices at household level and sociodemographic factors. Using multinomial regression analysis, sociodemographic characteristics, including the gender of the household head, income of the household, occupation, and education level, were compared for water safety risk practices relative to low water safety risk, given the other variables in the model are held constant (Table 3). The multinomial logit for females relative to males was −0.061 unit less for

Table 3. Sociodemographic determinants of water safety risks.

RISK OF WATER SAFETY PRACTICE	COEFFICIENT	*P*-VALUE	RRR
Low risk	*(Base outcome)*		
Medium risk			
Gender of the household head	−0.0609	*	0.9408
Marital status	−0.1922	*	0.8252
Education	0.01120	*	1.011
Religion	0.0535	*	1.055
Income	0.1782	*	1.195
Occupation	−0.0705	**	0.9319
High risk			
Gender of the household head	−0.5269	*	0.5904
Marital status	0.0274	*	1.028
Education	0.2075	*	1.231
Religion	0.15921	*	1.173
Income	−0.4685	*	0.6259
Occupation	−0.1673	**	0.8459

*$P > .05$. **$P = .01$.

medium risk and −0.526 unit less for high risk compared to low risk, implying that females are less likely than males to practice medium-risk and high-risk water safety practices. The analysis also shows that if a household increases its income by one unit, the log odds of practicing medium water safety risks increase by 0.18 compared to low-risk water safety practices ($P > .05$). However, if a household increases its income by one unit, the log odds of practicing high-risk water safety practices decrease by 0.47 ($P > .05$) while holding all other factors in the model constant.

Microbial quality of drinking water at the point of use. *E. coli* load in the drinking water at the source and point of use is presented as a box plot (Figure 3). In the current study, approximately 44% and 69% of the drinking water samples collected from the study households at the point of use and source respectively were negative for *E.coli*. According to the WHO standard guidelines for drinking water quality fourth edition,[8] drinking water is safe if it contains less than 1 CFU of *E. coli* per 100 ml of water, which is regarded as low risk, between 1 and 10 CFU, which is seen as intermediate risk, and more than 100 CFU, which is regarded as high risk. Water that contains more than 100 CFU/100 ml of E. coli is regarded as having a very high risk.

Therefore, in the drinking water at the point of use, the remaining 56% of the samples had a low risk of

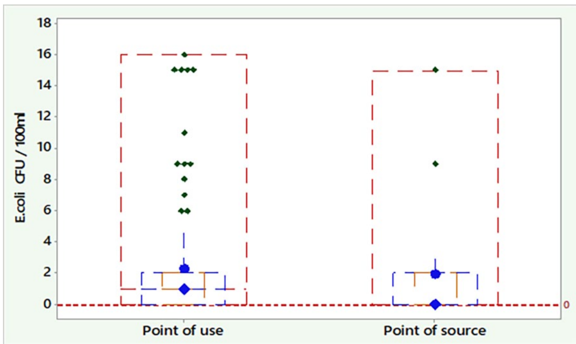

Figure 3. E. coli load in the drinking water at the point of source (n = 14) and at the end of use (n = 117).
The horizontal line at $y = 0$ shows the WHO standard limits of *E. Coli* in drinking water; the big box is a range box; the middlebox is an IQR box; the inner box is the CI for median; the diamond and circle blue boxes are median and mean values, respectively; the green dots are individual outlier values.

contamination, and 7% were at high risk. This study found that the average *E. coli* load at the point of use was 2.6 ± 5 CFU/100 ml with a minimum *E. coli* load of 0 CFU/100 ml in 7% of the households and a maximum of 40 CFU/100 *E. coli* in a single household. The *E. coli* load at the point of source ranged between 0 and 15 with an average number of 1.94 + 4.19 CFU/100 ml, and the *E. coli* there was a significant difference of *E. coli* concentration between the point of use and point of source ($P < .001$).

One-sample *t*-test analysis shows that the *E. coli in the drinking water sample at the* point of use was significantly different from the WHO microbiological standard for drinking water (t (115) = 5.6, $P < .001$). However, the water quality as CFU load at the point of source did not vary significantly from the WHO drinking water quality standard (t (15) = 1.85, $P = .08$).

Domestic water-use practices and water safety risks. The household's risks of water safety practices were evaluated at the point of use using the WHO water safety guidelines. For the analysis, the practices were categorized into low risk, intermediate risk, high risk, and very high risk. Accordingly, most of the households (243, 64%) were at low risk, followed by 34% (131) falling under the intermediate risk level and only small portion of households (8, 2%) facing a high risk of water safety. Based on the fourteen-point water safety practice observational checklists adapted from the WHO water safety plan manual,[17] none of the households were categorized as very high risk.

The water collection containers in most households (343, 89%) were free from any leaks, in most (273, 68%), not used for storing liquids other than water, and 84% of them were kept in a place where it may not be exposed to contamination. This implies that most households' practices associated with water collection containers were safe. However, approximately in half of the respondents' households, the collection container was not adequately covered to prevent the entry of contaminants. In a small number of households (41, 11%), the collection

Table 4. Factor analysis of the practices and risks of water safety in a domestic environment (n = 384, F = factor).

NO.	VARIABLE	F-1	F-2	F-3	F-4	F-5	COM
1	Is the water collection container cracked, leaking, or unclean?	0.782					0.593
2	Is the inside of the storage container unclean?	0.650				0.670	0.504
3	Are there any visible signs of contaminants in the bulk storage?	0.631					0.468
4	Does the collection container leak, or is it unclean?	0.624					0.434
5	Is the tap used to draw water from the final storage inadequate?		−0.868				0.458
6	Is the collection container inadequately covered?		−0.813			−0.766	0.683
7	Is the cup used to draw water from the bucket unclean?		−0.740				0.616
8	Is the collection container used to store liquids other than water?		−0.642				0.660
9	Did s/he wash cups before taking out water?			0.765			0.662
10	Does she/he wash their hands before taking out water?			0.662		0.667	0.617
11	Is household-level water treatment practiced?			0.574			0.657
12	Does the drinking water container have a wide mouth?				0.776	0.666	0.618
13	Does the drinking water storage container contain a cover?				0.556		0.566
14	Is there a leakage in the household /yard connection water tap?					0.809	0.703
	Variance	2.3380	1.8501	1.3959	1.3336	1.3201	8.2378
	% Var	0.187	0.152	0.132	0.105	0.094	0.670

PCA to extract factors, Kaiser Criterion to determine factor levels and varimax used for rotation, F = factor, Com = commonality.

containers had leaked on their surface. Moreover, in most households (377, 90%), the water containers remain open throughout or inadequately closed, implying that contaminants may get the chance to enter into the water containers and grow, resulting in health problems among the family members. Moreover, most study households (263, 68%) did not practice household water treatment. Although the absence of visible contaminants in the bulk container does not imply the water is safe, in 85% of the households, there were no visible contaminants during observation. In a few households (10%), the inside of the container looks unclean, indicating microbial growth inside.

Factor analysis was used to reduce the number of variables, group them, and identify the relative importance of the variables contributing to the risks of water contamination at the household level (Table 4). Accordingly, 1 to 4 inspection questions were about the hygiene condition of the collection container and storage (Factor 1), giving a mean loading value of 0.67. Thus, this factor describes water safety practice risks associated with the hygiene of collection and storage containers. Practices (5-8 sanitary inspections) were water withdrawal, and cover-related variables (Factor 2) have significant negative loadings with a mean value of −0.766, suggesting that the factor (the latent variable) has a negative linear association with the variables. Sanitary inspection variables from 9 to 11 (Factor 3) were cup-hygiene and treatment-related variables with a mean value of 0.667. So, this factor describes hygiene behavior aspects of the water safety practices in the household. Wide mouth container (0.776) and presence of cover (0.556) have significant positive loadings on factor 4 with a mean loading of 0.666, indicating the considerable effect of the latent variable on the observed variables. The factor analysis shows that almost all variables contribute equally to present risks in the water supply chain. All 5 factors explained 0.67 or 67% of the variation in the household-level water safety practice, with maximum variation explained by factors 1 and 2 being 18.7% and 15.2%, respectively.

Discussion

In this study, the diagnostic sanitary observations showed that the surface water sources (0.53) and the catchment (0.62) were at very high and high-risk levels, and the boreholes (0.44), water distribution system (0.4), water source boreholes(0.33) and Household level (0.29) water safety practices are identified as medium risk levels. Whereas water treatment (0.05) and temporary reservoir (0.2) were at low-risk levels. All 3 surface water sources are located close to Addis Ababa and Sheger City, where urbanization is rapidly occurring.[18] Several reports indicated the severe impacts of urbanization on the quality of aquatic resources and their catchments.[19-21] In the present study, different industries have been established a few kilometers away from the primary surface water sources, particularly surrounding Legedadi Reservoir. Industrial activities can emit contaminants into the air and water, polluting drinking water sources.[15] Moreover, everyday agricultural activities surround the water sources and reservoirs, and many researchers have reported the effect of agriculture and livestock on the primary water supply source.[21-23] Several researchers have documented the detrimental consequences of livestock near drinking water sources.[24-26] Drinking water sources can also be contaminated by agricultural practices such as using pesticides and fertilizers.[16,17]

Although the boreholes in this study were at low-risk levels, livestock rearing, agricultural activities, and surface water discharge were shared, which later increased the turbidity and may also carry dangerous bacteria. Shallow boreholes are more prone to pollution in highly permeable solids or fractured rock aquifers. According to the WHO risk factor score, the Akaki-Kality boreholes are safer than surface water sources at the source level and independent of the treatment impact, which indicates that the boreholes were at low risk of contamination. Because deep aquifer groundwater is shielded from pathogen contamination by the surrounding soil layers, it is often more protected than surface water.[27,28]

The catchment failed 7 of the 13 inspection questions in the present study, implying that it presented 62% risk. Discharging untreated industrial waste, agriculture, animal husbandry, solid waste, and road runoff were identified as the significant risk practices in the catchment. Previous reports show the impact of anthropogenic activities on the catchments of Legedadi and Gefersa Reservoirs.[29,30] Catchment areas are essential to guarantee the quality and quantity of drinking water supply. The results of several studies demonstrate the connection between the catchment area and the surface water quality.[28-34] The catchment region impacts drinking water quality in several ways, including land development, weather, the presence of buffer zones, and size and location.[29] High concentrations of biogenic substances, such as total phosphorus, nitrate nitrogen, and ammonium nitrogen, found in agricultural waters flowing into water sources and derived from organic and mineral fertilizers,[29] cause algal blooms in drinking water sources.

In the present study, the leading risk factor identified in the water treatment was problems linked to backwashing and staff safety, presenting a 5% risk. When backwashing a drinking water system filter, the water flow is reversed and increased to remove accumulated trash and particles. Backwashing is essential to a filter's lifespan and the caliber of the water it produces.[21] Drinking water quality is directly impacted by rate, duration, timing, filter type, hydraulics, and volume.[21-23] According to several publications, backwashing directly and indirectly impacts water safety.[24-27]

In the present study, the significant risks related to the distribution system were exposed pipes, illegal connections, poor water distribution pipeline repair, and contaminants drawn into the system. Distribution system wear and tear can pose intermittent or persistent health risks.[31] Water quality deterioration in the distribution system can be caused by several factors, such as biological stability, cross-connection, deterioration of buried infrastructure, permeation and leaching, nitrification, microbial growth and biofilm, water storage facilities, and water age.[32] Water distribution systems can be damaged when new pipes are added or aged. According to the USA CDC, as water distribution systems age, deterioration can occur due to corrosion, which causes water leakage, erosion of materials, and external pressures.[33]

Improved drinking water and sanitation indicated that household head and socioeconomic factors significantly affect access to improved drinking water sources. A similar study showed that female-headed households, households with heads with at least attained middle-school-level education, urban households, and better-off households had a higher probability of accessing improved drinking water.[34] Previous research has also shown that a household's preference to access safe water in Africa was associated with several factors, including the place of residence, wealth status, education, ethnicity, access to electricity, gender, water collection time, and the number of rooms in a household.[35-37] A systematic review of 57 studies on microbiological contamination of drinking water between source and point-of-use showed that more than half of the studies reported drinking water contamination at the household level due to poor domestic water safety practices.[38] Biological contaminants, once entered into the container, depending on other environmental factors, may get a chance to grow into a biofilm.

Conclusion

According to the WHO drinking water standards, the water-service supply chain of Addis Ababa city has low to very high-risk levels of contamination from the water source and catchment, treatment process, temporary water service reservoir, and distribution systems. This means that consumers can get infections from contaminated water. The findings suggest urgent water safety interventions are needed along the water supply service chain. These are hygienic water handling at the household level, integrated watershed management at the source, proper repair and maintenance of distribution pipelines, and water safety awareness raising education for the public.

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Author Contributions

SFS Conceived the idea, collected the data, drafted, and reviewed the manuscript. SRG supported data analysis and reviewed the manuscript. AA designed the study, analyzed the data, and reviewed the manuscript.

Availability of Data and Materials

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

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