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Determinant Factors of Microbial Drinking Water Quality at the Point of Use in Rural Ethiopia: A Case Study of the South Gondar Zone

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Abstract: Access to safe drinking water is a fundamental human need for health and well-being implemented globally by the United Nations under Sustainable Development Goal (SDG) 6. Storing drinking water is common in rural areas of Ethiopia due to off-premises water sources and intermittent piped water supply. However, this practice can lead to further contamination during collection, transport, and storage, posing a risk to public health. The objective of this study was to identify the determinant factors of drinking water quality at the point of use in the rural setting of northwestern Ethiopia, South Gondar zone. A questionnaire survey was conducted, and water samples from 720 households were collected during the wet and dry seasons. The determinant factors were identified using the multivariable logistic regression model. About 39.2% of the surveyed households had basic water supply services, 41.9% were using unimproved sources, and 8.3% were using surface water. Only 9.4% were using basic sanitation services, and 57.2% were practicing open defecation. Safe water storage was practiced by 84.3% of households, while only 2% engaged in household water treatment. About 14% of dry and 8% of wet season samples from the storage were free from fecal coliform bacteria. Furthermore, 52.9% of dry and 62.2% of wet season samples fell under the high microbial health risk category. The season of the year, the water source type, storage washing methods, and the socioeconomic status of the household were identified as key predictors of household drinking water fecal contamination using the multivariable logistic regression model. It was observed that the drinking water in households had a high load of fecal contamination, posing health risks to consumers. To tackle these problems, our study recommends that stakeholders should enhance access to improved water sources, implement source-level water treatment, increase access to improved sanitation facilities, advocate for safe household water management practices, and endorse household water treatment methods.

Keywords: contamination; fecal coliform bacteria; household; storage; water quality

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1. Introduction

Storing water within households becomes necessary when access to safe drinking water is intermittent and water sources are off-premises. However, this practice of storing water at home can potentially lead to contamination and thereby challenge the provision of safe drinking water as a fundamental human right [1]. Loss of disinfectant, formation of disinfectant byproducts, production of odor and test, leachate from the container's internal surface, intrusion of microorganisms, and facilitation of microbial growth are among the problems caused by storing water [2]. Contamination of drinking water in the water storage at the household level was identified as the most important pathway of pathogens to humans [3].

In low- and middle-income countries, the majority of the population lacks accessibility and reliability of safely managed drinking water. As of 2022, the percentage of safely managed water supply service coverage in Ethiopia stood at approximately 13.2%, with a significantly lower rate of 5.8% among rural communities. On the contrary, 70% and 21.8% of the rural population had unimproved sanitation services and practiced open defecation, respectively [4]. The United Nations 2030 Agenda for Sustainable Development emphasizes the importance of water resources under Goal 6, clean water and sanitation [5]. As a member country that has adopted the United Nations 2030 Agenda for Sustainable Development, Ethiopia has committed to fully implementing the agenda without any exclusions [6]. However, Ethiopia is not on track to achieve access to safely managed drinking water services for the whole population [4].

The community's access to safe drinking water is greatly impacted by sanitation practices. Poor sanitation and low levels of hygiene are the main factors for bacteriological contamination of water during collection, transport, and storage in the house [7]. The main factors of diarrheal disease are unsafe water supply and improper sanitation practices [8]. Improper water, sanitation, and hygiene (WASH) in 2016 led to 829,000 diarrheal deaths, with a major contribution from unsafe drinking water, mainly in sub-Saharan Africa [9]. A study conducted in Wogeda town, northwest Ethiopia, revealed a 58% prevalence of water-borne disease [10]. There was a higher prevalence of diarrhea, fever, and cough in households with less access to improved WASH facilities [11]. The study conducted in Bangladesh revealed an association between diarrhea episodes among children under 5 years old and high *Escherichia coli* (*E. coli*) contamination in households [12]. Similarly, a study conducted in slum areas of Hawasa city revealed that the odds of diarrhea occurrence is 17.3 more for households positive for fecal coliform bacteria (FC) detection in the drinking water [13]. Collecting water from unimproved sources, not treating drinking water, lack of toilet facilities or using unimproved toilet facilities, and improper waste removal are among the most consistent WASH-related factors associated with diarrheal disease in Ethiopia [14].

In order to evaluate national efforts to achieve safely managed drinking water services in accordance with Sustainable Development Goal (SDG) 6 by 2030, expanding drinking water quality monitoring and management practices is necessary. For this purpose, free from microbial contamination implies that fecal coliform bacteria should be nil per 100 mL drinking water sample [15]. Regular water quality monitoring in sub-Saharan Africa primarily emphasizes the assessment of piped water supply, resulting in limited availability of water quality data for rural areas where improved water sources other than piped systems are used. Additionally, data are scarce for household storage units since the responsibility of service providers typically ends at the water points, leading to an infrequent collection of samples from household storage containers [16]. With comprehensive household surveys and water quality testing, it is possible to identify the predicting factors for household drinking water deterioration.

In the study area, a significant portion of the population resides in rural areas where the main sources of drinking water are hand-dug wells and springs. Piped water supply, on the other hand, is typically intermittent and primarily available in the towns. As a result, households in the study area are compelled to store drinking water. However, it is important to note that water stored in households may be susceptible to further contamination during the processes of collection, storage, and household use. This study aimed to identify determinant factors of microbial drinking water quality at the point of use in rural Ethiopia and assess the water supply and sanitation service level of households. Notably, this study fills a research gap by examining the impact of households' practices on drinking water quality at the district level, making it unique within the study districts.

2. Materials and Methods

2.1. Description of the Study Area

The Farta and Dera districts are located in the South Gondar zone, Amhara regional state of Ethiopia, shown in Figure 1. Both districts are positioned in the northwest highlands of Ethiopia. The Farta district spans between the coordinates 11°40′ and 12°2′ N and 37°50′ and 38°18′ E, and the Dera district spans between the coordinates 11°17′ and 11°54′ N and 37°59′ and 37°26′ E.

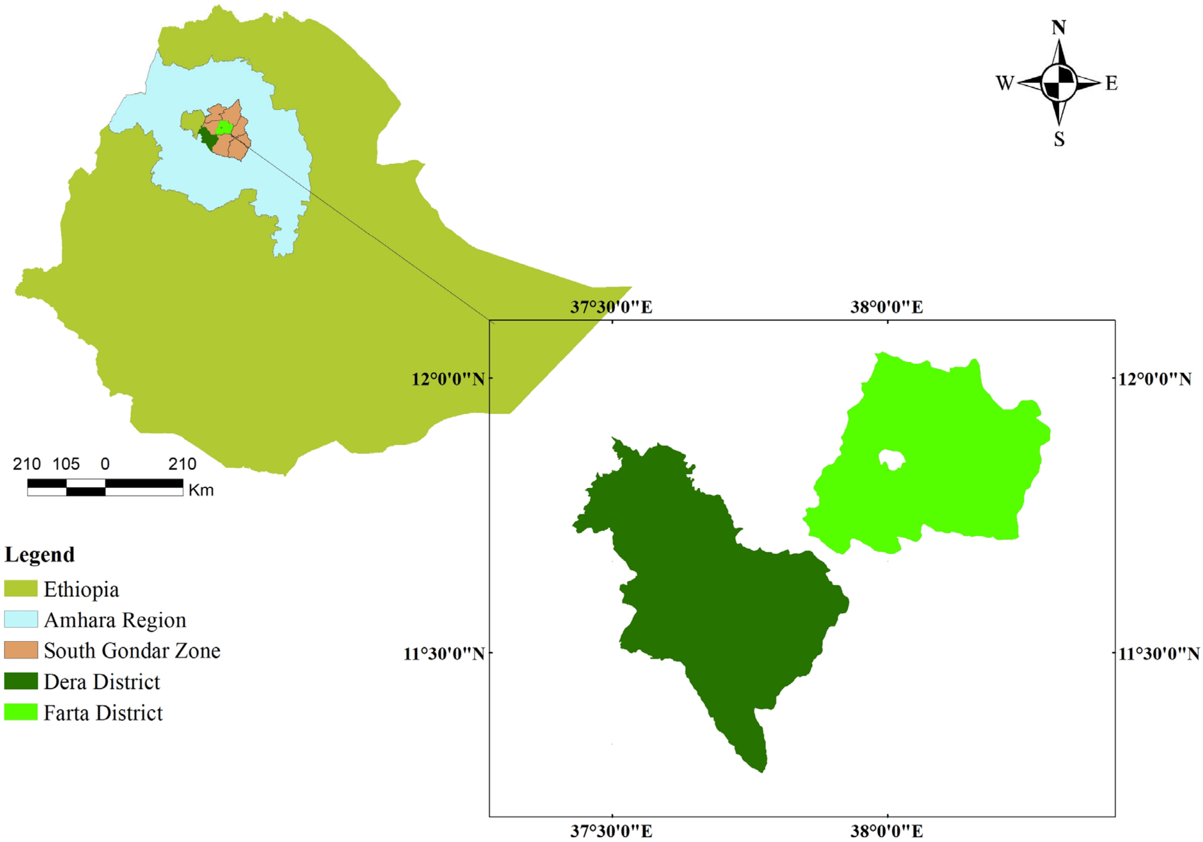

Figure 1. Geographical location of the study area.

The Dera district is characterized by diverse land topography, with 35% of the landmass being flat, 27% rugged terrain, 20% mountainous, and the remaining are hills, valleys, and others. The region experiences an annual rainfall ranging between 1000 and 1500 mm and an elevation range of 560–3200 m above sea level [17]. Over 50% of the land in the Farta district is Woynadega middle land, featuring a relatively even terrain ranging from 1900 to 2300 m above sea level. The remaining area is divided between Dega mountainous highland, ranging from 2300 to 3200 m, and Wurch (cold) land, spanning an elevation of 3200 to 4035 m. The district experiences an annual rainfall between 1097 and 1954 mm, with a long-term average of 1248 mm [18]. The average annual temperature is 15.5 °C. The Farta district is located surrounding the zonal city, Debre Tabor. According to the central statistics agency, the population of the Farta district is estimated to reach 234,143 in 2022, with the majority residing in rural areas, specifically 187,307 people. Similarly, the population of the Dera district is projected to be 304,204, with the majority (270,895) residing in rural areas [19].

2.2. Sampling Size

This study is part of the Conrad N. Hilton Foundation Africa Water Quality Testing Fellowship Program. Household selection followed a two-stage selection process. In the first stage, 18 kebeles were selected from each district, and each selected kebele was represented by a single enumeration area (EA). The selection of enumeration areas (EAs) was performed using population-proportional-to-size random sampling [20], where enumeration areas with larger populations were more likely to be selected. In the second stage, household surveys were planned for 10 randomly selected households in each enumeration area. The household selection process involved several steps. Firstly, shape files (GIS-based maps of enumeration areas) were acquired from the national statistical authority. These shape files were then overlaid with a settlement layer in Google Earth to identify populated areas within the enumeration area. Fourteen coordinates, including ten for the survey and four extras, were randomly chosen within the EA boundary. Afterwards, each selected GPS coordinate was adjusted to align with the nearest visible household structure by manually examining satellite images. In cases where multiple structures were found within the same radius from the chosen point, the coordinate was adjusted to the structure that appeared first when sweeping in a clockwise direction starting from the north.

The number of households to be surveyed in each district was determined based on an estimated margin of error of 5.1 percentage points on a binary measure (assuming 90% confidence, intra-cluster coefficient of 0.1, and a prevalence of 10% based on baseline indicators). The following formula was used to determine the number of samples based on the aforementioned statistical criteria [21,22].

$$n = \frac{Z^2 \times P(1-P)}{E^2} \times 1 + (m-1) \times ICC$$

where:

- Z = score corresponding to the desired confidence (90%), z = 1.645;
- P = estimated prevalence of 10% based on baseline indicators;
- E = desired margin of error (5.1%);
- m = average cluster size (numbers of households per cluster, 10);
- ICC = intra-cluster correlation coefficient (0.1).

Based on the above formula, a minimum of 178 households should be included for each district in every season. In this study, a total of 180 households were surveyed in each district, and water samples were collected from the drinking water storage of each household. Additionally, if the selected household had an improved water source on their premises, a secondary sample was taken from that source. The study was conducted across both the wet and dry seasons, resulting in a total of 720 households being surveyed.

2.3. Sample Collection and Analysis

Pretested structured questionnaires and in situ observations were used to collect data. The questionaries were prepared by reviewing the relevant literature and organized into four parts: (1) socioeconomic survey, (2) drinking water sources, (3) household water handling practice, and (4) sanitation practice. The socioeconomic questionnaires were adopted from the USAID Demographic and Health Surveys (DHS) Program. An interview was conducted with either the family head or a family member aged 18 years or older who was present during the data collection period. Informed consent was obtained prior to the interview from all participants. The survey and sample collection were conducted during the wet season, from 19 August to 8 September 2022, and in the dry season, from 4 March to 18 March 2023.

In each household, only fecal coliform bacteria and free chlorine residual (FCR) were tested using a single, non-duplicate sample. The survey was conducted using the mWater (Version: 67.0.0) mobile application. Sterilized Whirl-Paks, provided with sodium thiosulfate for dechlorination in cases where samples were taken from chlorinated water, were used to collect the required 100 mL samples for the FC test. The samples for the FC test were transported to a central laboratory at Bahir Dar Technology Institute using the icebox to keep the temperature below 4 °C. The fecal coliform bacteria test of the samples was carried out within six hours from the collection time of each sample. The membrane filtration method was used to test the fecal coliform bacteria in samples [23]. A 100 mL sample was vacuum filtered through 45-micron sterile millipor s-pack type HA membrane filters (HACH, Manchester, UK). Subsequently, the membrane filter containing the retained particles was placed in a petri dish with a membrane pad saturated with culture media (membrane lauryl sulfate broth) that is selective for FC. The prepared petri dishes were then transferred to an incubator that maintained 44 °C for a period of 24 h. Following the incubation, the yellow colonies (FC) were counted, and the resulting data were recorded [13,24]. However, in the case of excessively turbid water samples, the filtration process encountered difficulties. In such instances, a reduced volume from the sample was filtered instead. The results were subsequently adjusted with a corresponding dilution factor.

The amount of free chlorine residual was measured using a LaMotte Octaslide Chlorine Tester Equipment (Lamotte, Chestertown, MD, USA). After three thorough rinses with the water to be tested, a test tube was filled to the 5 mL line with sample water, and one DPD 1R tablet was mixed and stirred until the tablet dissolved. The test tube was then placed into an Octaslide viewer, which was then held to prevent light from entering the viewer from the back. The test tube's color was then compared to a standard color and recorded as mg/L of free chlorine residual [25,26].

2.4. Quality Control

Quality checks were in place for multiple stages of data collection. These were built-in checks in the mWater platform to prevent enumerators from continuing the survey without answering questions or recording that the respondent did not want to answer a question, and there was a list of checks to complete each day while reviewing new data (common-sense checks on number of surveys completed, duration of surveys, number of water samples collected, GPS location of institutions, verification of certain responses based on photos).

The accuracy of the analysis procedure was verified by analyzing blank samples with known parameter values. This ensured that any variability in the results obtained was not due to errors in the laboratory analysis or sample collection procedures. Every Wednesday, a field blank sample was taken from a sealed water bottle and tested for FC to ensure the sample collection procedure. Additionally, a laboratory blank was examined daily, along with the sample's FC test, to ensure the quality of the membrane lauryl sulfate broth and the integrity of sample analysis techniques. Furthermore, training sessions were conducted for data collectors and laboratory technicians to improve data quality. Blank samples underwent evaluation for the presence of FC. In the event of a positive result, the findings were compared to other samples processed on the same day. Samples showing FC counts lower than the blank sample were either disposed of or subjected to retesting after recollection.

2.5. Data Analysis

To determine if the water quality complied with standards, the measured FC count and free chlorine residual of the water were compared to national and international drinking water standards. The Ethiopian drinking water quality [27] and the World Health Organization (WHO) guidelines for drinking water quality [28] were used to evaluate the drinking water quality. The FC count of drinking water should be nil, and FCR should be found at a minimum level of 0.2 mg/L to protect the water from further contamination.

The level of FC present in a 100 mL sample was used to determine the associated health risks of consuming the water. For all samples, FC counts were performed up to 100 CFU/100 mL. If the number of FC exceeded 100 CFU/100 mL, the sample was recorded as 101, which means "too numerous to count" (TNTC). A color code system was implemented to enhance comprehensive understanding. In this system, a blue color code represented the absence of FC detection (<1 CFU/100 mL), indicating a safe category. The green color code (1–10 CFU/100 mL) indicated a low-risk category, the yellow color code (11–100 CFU/100 mL) represented an intermediate-risk category, and the orange color code (101–1000 CFU/100 mL) denoted a high-risk category [29,30].

R programming language (R 4.2.3, RStudio 2023.12.1) (R Foundation for Statistical Computing, Vienna, Austria) was used to perform all statistical analyses. The socioeconomic status, drinking water sources, household water handling techniques, and sanitation practices were assessed using simple Chi-squared analysis followed by a multivariable logistic regression analysis to examine the determinant factors of microbial quality of household storage drinking water. The Chi-squared test was used to assess categorical data and whether a statistically significant difference exists among categories with a significant level of 0.05. A multivariable logistic regression model was developed to identify predictors of household drinking water quality. The model reported adjusted odds ratios (AORs) with 95% confidence intervals (CIs), along with the significance level. Multicollinearity among the independent variables was evaluated by calculating the variance inflation factor (VIF), and only variables with VIF < 5 were incorporated into the model. The model's goodness of fit was assessed using the Hosmer–Lemeshow test ($p > 0.05$).

2.6. Ethics Statement

This study adheres to all relevant ethical standards and guidelines for research involving human subjects, as well as environmental considerations. Ethical approval for the study was obtained from the Institutional Review Board (IRB) of the College of Medicine and Health Sciences at Bahir Dar University (Protocol No.: 537/2022, dated 4 October 2022). The Regional Water and Energy, Health, and Education Bureaus provided a support letter to the district's Water, Health, and Education Bureau to facilitate necessary collaboration for the study. In turn, the district health and education bureau sent letters to the respective healthcare facilities and schools requesting their cooperation.

3. Results

3.1. Household Survey

The survey was conducted during the wet and dry seasons, with additional questionnaires administered during the dry season ($n = 360$) (results in Table 1), and Table 2 contains the survey results of both seasons ($n = 720$). According to the household survey, the mean family size was five, with a standard deviation of 1.8. The households were classified into five socioeconomic groups based on their wealth level. The socioeconomic classification ranged from Q1 (representing the poorest households) to Q5 (representing the richest households) (Table 1).

Table 1. Household survey results for questionnaires asked during the dry season only ($n = 360$).

Questions	Variable	Frequency	Proportion (%)
What is the main source of drinking water for members of your household at this time?	Piped water to yard/plot	27	7.5
	Piped to neighbor	8	2.2
	Public tap/standpipe	1	0.3
	Tube well or borehole (with hand pump)	7	1.9
	Protected dug well with hand pump	74	20.6
	Protected dug well	14	3.9
	Protected spring	48	13.3
	Unprotected dug well	22	6.1
	Unprotected spring	129	35.8
	Surface water	30	8.3
Where is this main drinking water point located?	Elsewhere	318	88.3
	In own yard/plot	42	11.7

Table 1. *Cont.*

Questions	Variable	Frequency	Proportion (%)
Is the collection time less than 30 min for a round trip?	Yes	267	74.2
	No	93	25.8
Was sufficient water available in the last 30 days?	Yes, always sufficient	299	83.1
	No, at least once	60	16.7
	Do not know	1	0.3
When was the last time someone in your household cleaned this container?	Today	151	42.2
	Yesterday	124	34.6
	2–6 days ago	47	13.1
	1–4 weeks ago	24	6.7
	More than 1 month ago	6	1.7
	Never	1	0.3
	Do not know	5	1.4
How was the container cleaned the most recent time?	With soap and water (with or without a cloth or sponge)	84	23.9
	By shaking sand or rocks inside	70	19.9
	Water and a cloth or sponge	7	2
	Water and grass or leaves	117	33.2
	Water only	73	20.7
	Do not know	1	0.3
What kind of toilet does the household use?	Flush or pour-flush toilet	2	0.6
	Pit latrine	152	42.2
	No facility/bush/field	206	57.2
What kind of pit latrine is used?	Ventilated improved pit latrine	3	2
	Pit latrine with slab	43	28.3
	Pit latrine without slab/open pit	106	69.7
Is the toilet facility shared with other households?	Yes	29	18.8
	No	125	81.2
The socioeconomic quintile of the household	1 (poorest)	75	20.8
	2	117	32.5
	3	90	25
	4	47	13.1
	5 (wealthiest)	31	8.6

The study showed that a variety of water sources were used for drinking. Of the surveyed households, 35.8% were using unprotected springs (UPSs), 20.6% were using protected dug wells with hand pumps (HDWs), 13.3% were using protected springs (PSs), 8.3% were using surface water (SW), and the remaining were using piped water to yard (YT), unprotected dug wells (UPDWs), protected dug wells (PDWs), piped to neighbor (PTN), boreholes (BHs), and public taps (PTs) (Table 1). According to the WHO/UNICEF Joint Monitoring Program (JMP)'s water supply service ladder for households, a significant portion of the surveyed households (41.9%) relied on unimproved water sources, and 8.3% were using surface water. About 39.2% had access to basic water services, and only one household had safely managed water supply services (Figure 2a). The majority of households had no access to water on their premises, with only 11.7% reporting having water in their yard. About 25.8% of households spend more than 30 min collecting water. Despite the observed shortage of an improved drinking water source, 83.1% of the households reported having sufficient water, while the remaining reported experiencing water shortage at least once in the 30 days prior to the survey.

Table 2. Household survey results for questionnaires asked during both the wet and dry seasons (n = 720).

Questions	Variable	Frequency	Proportion
Does the storage have an opening big enough to dip a cup in?	Yes	88	12.2
	No	632	87.8
Does the storage have a lid that covers it?	Yes	691	96
	No	29	4
How was water removed from the container?	Dispensing from tap in storage container	2	0.3
	Dipping or scooping a cup or bowl	83	11.6
	Poured from container	632	88.1
Is the water storage considered as safe storage?	Yes	607	84.3
	No	113	15.7
Is there anything done to this water to make it safer to drink?	Yes	14	2
	No	703	98
What do you use or add to make this water safer to drink?	Chlorine (Aquatabs)	7	50
	Use a filter (biosand, ceramic, other filter)	2	14.3
	Let it stand and settle	3	21.4
	Strain it through a cloth	2	14.3
Is the treatment method practiced adequate?	Yes	9	1.3
	No	5	0.7
	No treatment	703	98
When was the sampled water collected from the source?	Before yesterday	65	9.1
	Yesterday	281	39.2
	Today, but more than 4 h ago	150	20.9
	Less than 4 h ago	219	30.5
	Do not know	2	0.3

About 12.2% of the surveyed households had a wide mouth storage, which allows for dipping a cup (Table 2). In terms of fetching water from the storage, the majority of households (88.1%) were using the pouring method, and 11.6% were still using the dipping method. About 96% of households had a storage with a cover (lid). The study revealed that the majority of households surveyed (84.3%) were using safe storage to store their drinking water. Safe drinking water storage is a container that prevents water recontamination, with features such as a narrow opening to prevent cup dipping or a tap for easy dispensing and a protective lid [31].

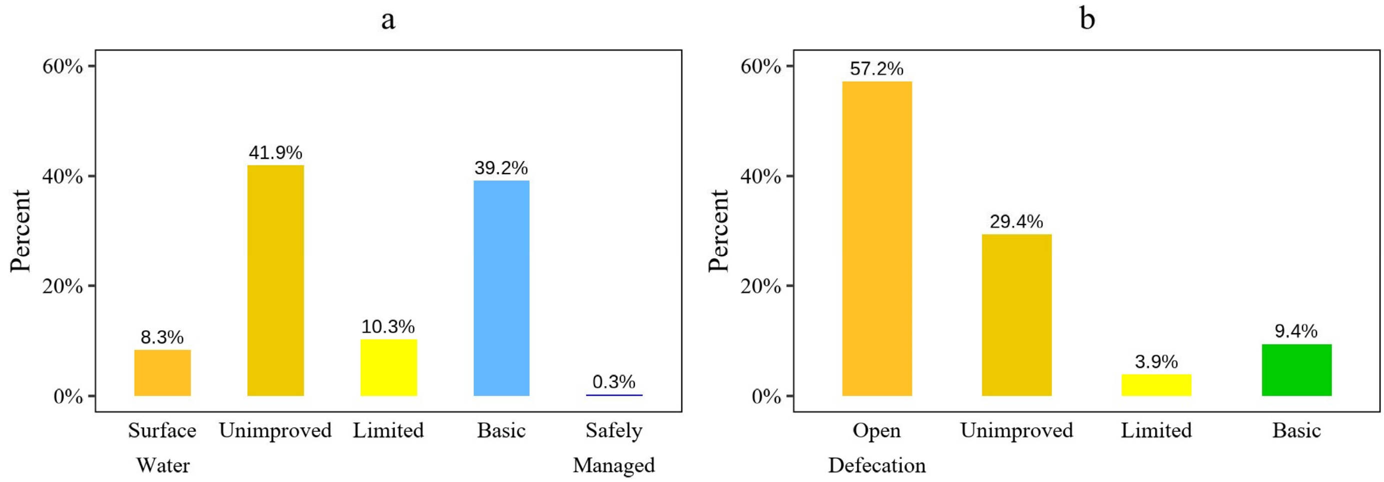

Figure 2. The percentage of (**a**) drinking water supply service ladders and (**b**) sanitation service ladders in the study area.

A very small percentage of surveyed households (2%) were able to treat their drinking water, and even among them, only 1.3% used adequate treatment methods such as biosand/ceramic or other filters and chlorine. The remaining 0.7% used inadequate methods, such as allowing it to settle and straining it through a cloth. About 39.2% of households had collected water one day prior to the survey, while 30.5% had collected water just four hours prior. The majority of households (42.2%) reported cleaning their water storage before collecting water, while 34.6% cleaned it one day before collection, and 13.1% cleaned their storage 2–6 days ago. About 33.2% of households were using grass or leaves to clean their storage, 23.9% were using soaps, 20.7% were using water only, 19.9% were cleaning by shacking sands or rocks inside the storage, and the remaining were using cloth or sponges (Table 2).

The majority of the surveyed households (57.2%) were practicing open defecation, 42.2% were using pit latrines, and only two households were using flush or pour-flush toilets. Relatively, open defecation was more prevalent in the Dera district, with 76.7% of households practicing open defecation compared to 37.8% in the Farta district. Out of those who used pit latrines, 69.7% had open pits, 28.3% had pit latrines with a slab, and only 2% had ventilated improved pit latrines. Furthermore, of the households using toilet facilities, 18.8% were sharing with other families (Table 1). According to the JMP household sanitation service ladder, 29.4% of the households were using unimproved sanitation services, and only 9.4% of the households were using at least basic sanitation services (Figure 2b).

3.2. Microbial Quality of Household Storage

Free chlorine residual was not detected in any of the surveyed households. As depicted in Figure 3a, the results indicated a notable difference between the dry and wet seasons in terms of fecal contamination. During the dry season, 14% of the samples were found to be negative for FC detection, while this percentage decreased to 8% during the wet season. In the dry season, 52.9% of the samples were classified as high-risk, whereas this percentage increased to 62.2% during the wet season. Overall, only 78 (11%) households were able to drink water free from FC. The Chi-squared analysis showed that the FC results varied significantly across seasons, with ($p < 0.01$). About 12.3% of samples collected in the Farta district were free from FC, whereas this percentage decreased to 9.7% in the Dera district. Additionally, 47.8% of samples collected in the Farta district fell into the high-health-risk category, whereas this percentage increased to 67.5% in the Dera district (Figure 3b). Fecal contamination was significantly varied across the district according to the Chi-squared test ($p < 0.01$).

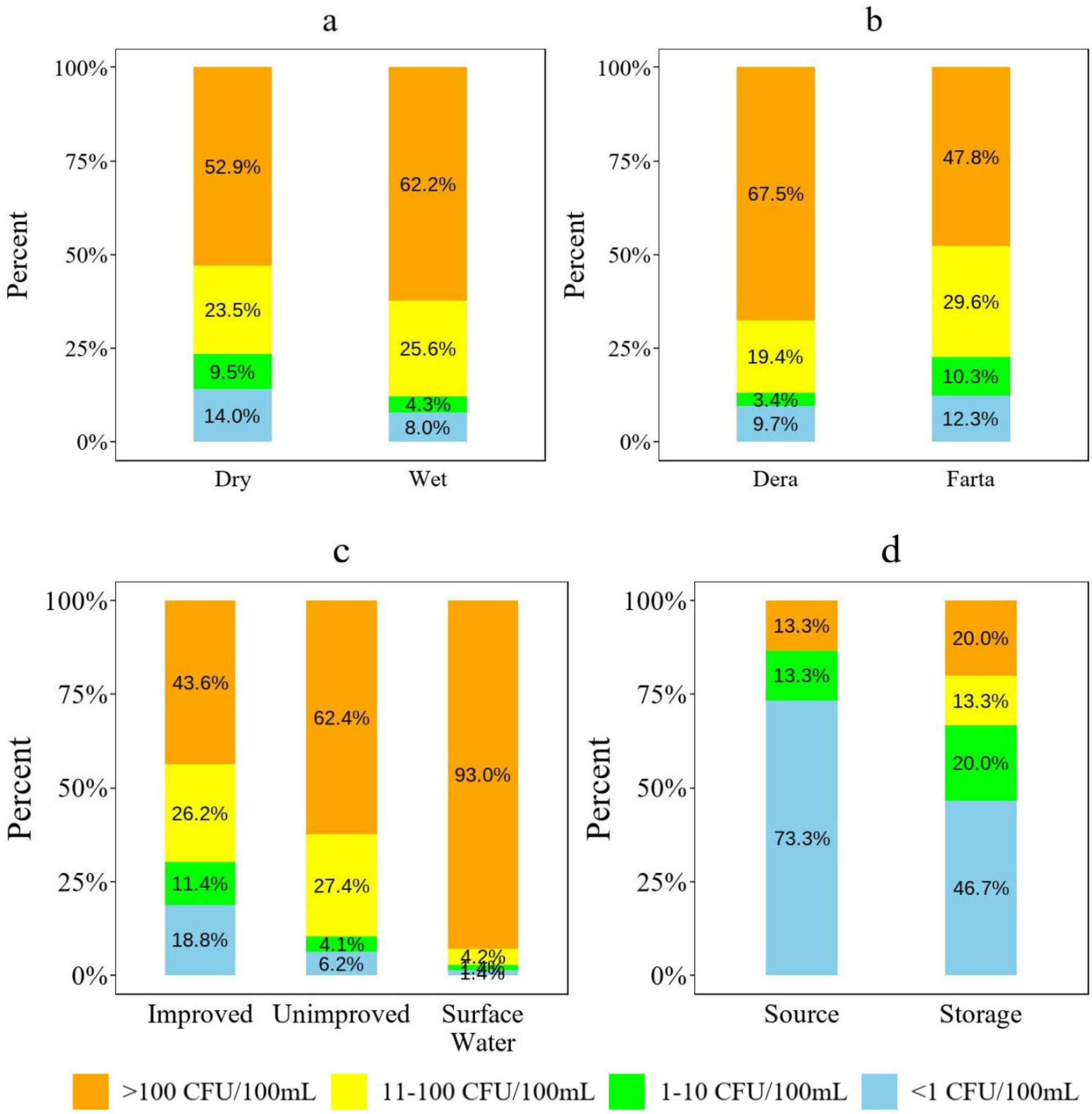

Figure 3. Variations in fecal coliform detection levels in household drinking water storage: (**a**) across the season, (**b**) across the districts, (**c**) among water points status, and (**d**) between the improved source in the yard and corresponding household storage.

The highest percentage of samples free from FC was observed in water obtained from a piped water supply, followed by BHs, PSs, PDWs, and HDWs. More than 50% of the samples sourced from PTs, BHs, and HDWs fell into the high-health-risk category, and more than 60% of samples sourced from rainfall collection (RC), UPDWs, UPSs, and SW fell into the high-health category (Figure 4). The variation of FC load among water sources was statistically significant according to the Chi-squared test ($p < 0.01$). The findings revealed that 18.8% of samples from improved sources were negative for FC detection, whereas this percentage decreased to 6.2% and 1.4% for unimproved and surface water sources, respectively. The proportions of samples that fell into the high-health-risk category were higher for surface water (93%), followed by unimproved sources (62.4%) and improved sources (43.6%) (Figure 3c). The FC load was significantly varied between improved, unimproved, and surface water household sources, with a Chi-squared test ($p < 0.01$).

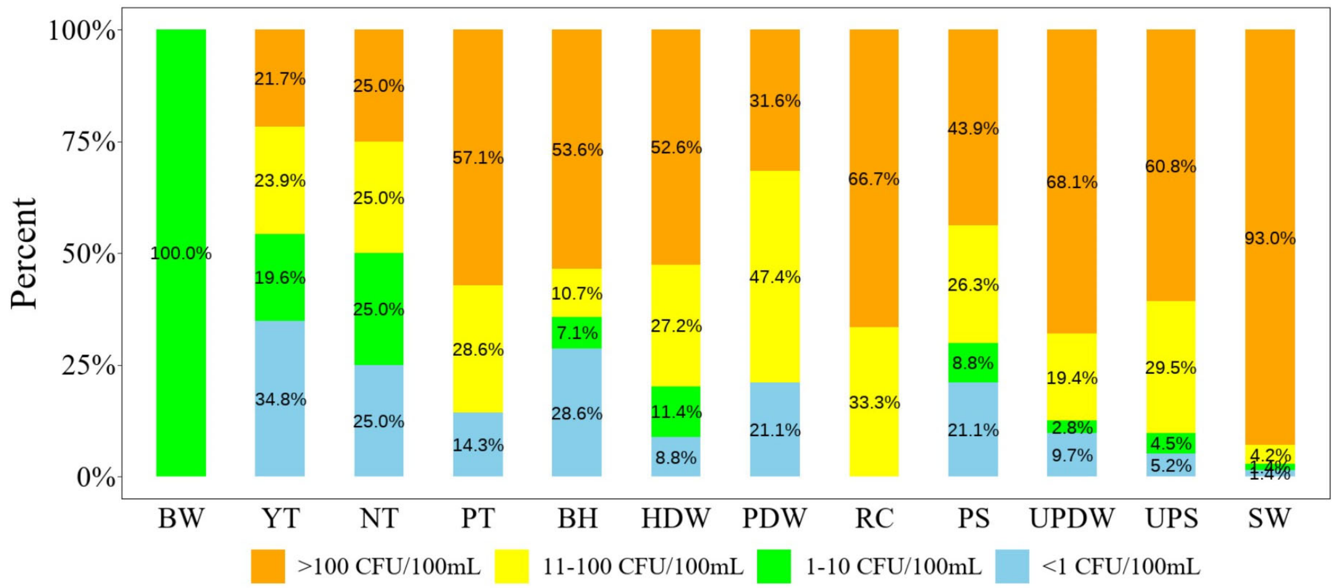

Figure 4. Fecal coliform detection level variation in the household storage regarding water points where the stored water is collected (BW: bottled water, YT: piped water to yard, NT: piped to neighbor, PT: public tap/standpipe, BH: borehole/tube well, HDW: protected dug well with hand pump, PDW: protected dug well, RC: rainfall collection, PS: protected spring, UPDW: unprotected dug well, UPS: unprotected spring, SW: surface water).

For households that had an improved water source in their yard and water was available during the survey (n = 15), a secondary sample was taken to assess the presence of further contamination in the storage. About 73.3% of samples taken from the improved source at the yard were free from FC (Figure 3d). However, this percentage decreased to 46.7% for the corresponding samples taken from the household storage, indicating a possibility of household contamination. Additionally, 13.3% of samples collected from improved sources in the yard fell into the high-health-risk category, whereas this percentage increased to 20% for corresponding household storage, indicating further contamination. However, there was no significant variation in FC load between the source in the yard and household storage with the Chi-squared test (p = 0.35).

Among the samples collected from safe storage, 11.5% were found to be free from FC (Figure 5a). In contrast, only 8.1% of samples from unsafe storage were free from FC. The percentage of samples categorized as high health risk was 64% for unsafe storage and 56.4% for safe storage. However, the variation in results was not statistically significant, as indicated by a Chi-squared test (p = 0.33). The study found that households using the dipping method to fetch water from storage had higher levels of FC load compared to those using the pouring method (Figure 5b). However, there was no significant difference in FC load among water withdrawal methods (p = 0.34, Chi-squared test). Households with narrow mouth storage had lower FC load compared to the wider one (Figure 5c). However, the variation was not statistically significant according to the Chi-squared test (p = 0.28).

Storing drinking water for a longer duration was associated with a higher percentage of samples negative for FC detection. Samples collected from containers that stored water prior to the day before the survey had a higher percentage (17.2%) of negative results for FC detection compared to samples collected earlier (Figure 5d). Furthermore, the proportion of samples classified under the high-health-risk category was lower (48.4%) for water collected before the day before the survey. However, the FC load did not show significant variation across different water collection times, as indicated by a Chi-squared test (p = 0.15).

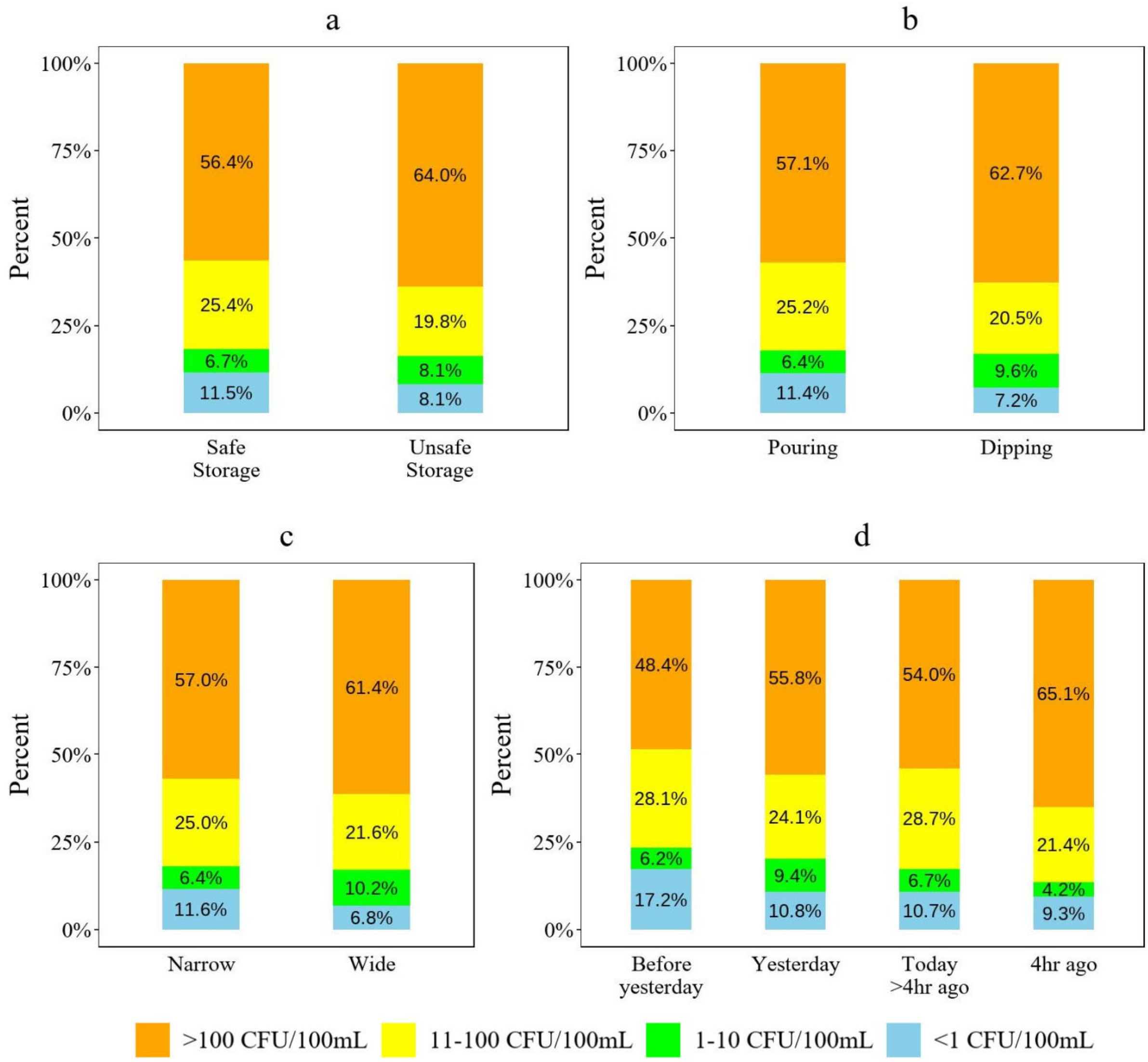

Figure 5. Fecal coliform detection level variation among (**a**) storage status, (**b**) water withdrawing method, (**c**) storage mouth opening, and (**d**) water collection time.

Among the treated water samples, 14.3% were negative for FC detection, while this percentage decreased to 10.9% for those who did not practice treatment. Additionally, 50% of the treated water samples fell under the high-risk category, compared to 57.7% for the untreated water samples (Figure 6a). The FC results showed a significant difference between the households that treated their drinking water and those that did not, with a Chi-squared test ($p < 0.05$).

The method used to wash drinking water storage had an impact on the water quality. Storage that was washed using soap had the highest percentage (27.4%) of samples free from FC contamination, followed by storage washed with water only (18.1%), sand or rocks (11.4%), and grass or leaves (5.1%) (Figure 6b). Furthermore, the percentage of samples falling under the high-health-risk category was significantly lower (35.7%) for storage washed using soap compared to the other washing methods. The FC load varied significantly among different storage washing techniques according to the Chi-squared test ($p < 0.01$). Water storage that was last washed more than a week prior to the surveying date exhibited a lower FC load in comparison to storage that was washed more recently (Figure 6c). However, there was no statistically significant variation in FC concentration across the last time when storage was cleaned, with a Chi-squared test ($p = 0.46$).

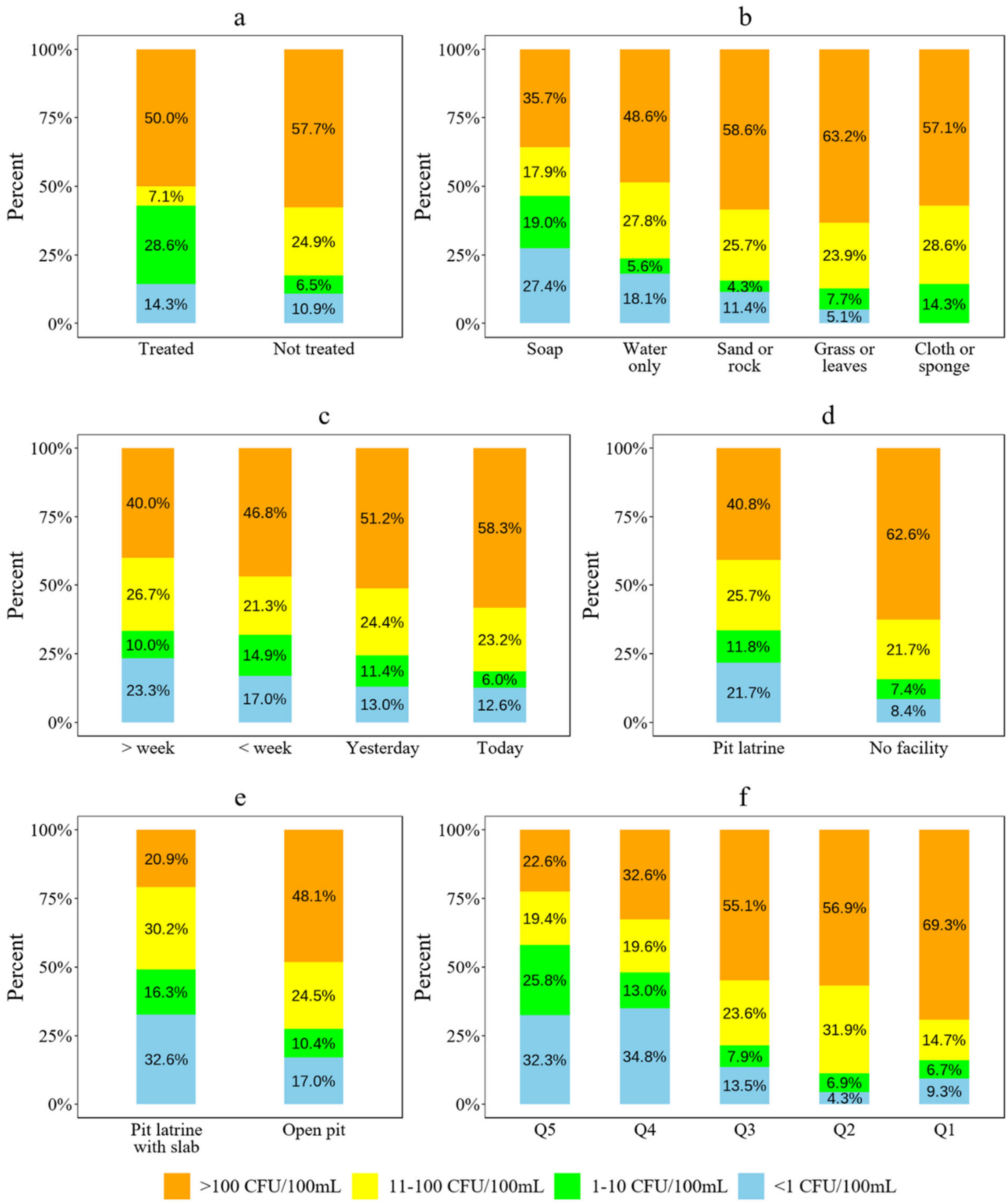

Figure 6. Fecal coliform detection level variation among (**a**) presence of household water treatment, (**b**) storage washing technique, (**c**) the last time the storage was cleaned, (**d**) presence of sanitation facility, (**e**) pit latrine type, and (**f**) socioeconomic status (Q5 is quintile 5 being the wealthiest 20% and Q1 is quintile 1 being the poorest 20%).

Household-level FC contamination shows significant variation between households that use latrines and those that practice open defecation, with a Chi-squared test ($p < 0.01$). The percentage of samples free from FC collected from households using latrines was 21.7%, which was higher than the percentage for households practicing open defecation (8.4%) (Figure 6d). Furthermore, the FC contamination level varied significantly among the types of pit latrines used by households, as indicated by a Chi-squared test ($p < 0.05$). The households using pit latrines with a slab had a higher percentage of samples negative for FC detection (32.6%) compared to households using open pits (17%) (Figure 6e).

The FC concentration level was significantly varied across the socioeconomic groups, as indicated by a Chi-squared test ($p < 0.01$). The findings showed that the high-income households had a higher percentage of samples free from FC (32.3%) compared to the low-income households (9.3%) (Figure 6f). Conversely, a higher proportion of samples from the low-income groups (69.3%) fell under the high-health-risk category compared to the high-income groups (22.6%).

Based on the results of the multivariable logistic regression analysis, the season of the year, type of water source, method of storage cleaning, and the socioeconomic group of the household were identified as significant predictors. During the wet season, there was a 1.8-fold increase in the likelihood of fecal-contaminated household drinking water [AOR = 1.828, 95% CI (1.092–3.118)]. Households that relied on unimproved water sources had a 3.7-fold higher likelihood of fecal contamination [AOR = 3.702, 95% CI (2.168–6.555)]. Similarly, households using surface water had a significantly higher risk of fecal contamination, with a 15.6-fold increase in likelihood compared to users of improved water sources [AOR = 15.642, 95% CI (3.245–281.561)] than improved water source users (Table 3). Compared to households that used soap for cleaning their water storage, those who employed grass/leaves had a 3.6-fold higher likelihood of fecal contamination [AOR = 3.591, 95% CI (1.312–11.036)]. Households categorized under socioeconomic group two had a 5.98-fold higher likelihood of fecal contamination compared to the wealthiest groups [AOR = 5.984 95% CI (1.602–24.941)] (Table 4).

Table 3. Multivariable analysis of factors associated with the presence of fecal coliform in household drinking water for the survey conducted during the wet and dry seasons (n = 705).

Variables	Fecal Contamination		AOR (CI:95%)	*p*-Value
	Negative	Positive		
District				
Farta	42 (11.8%)	313 (88.2%)	1	
Dera	34 (9.7%)	316 (90.3)	1.007 (0.606–1.68)	0.9787
Season				
Dry	28 (13.6%)	305 (86.4%)	1	
Wet	28 (8%)	324 (92%)	1.828 (1.092–3.118)	0.0237 *
Sample water source				
Improved	55 (18.6%)	241 (81.4%)	1	
Unimproved	20 (5.9%)	318 (94.1%)	3.702 (2.168–6.555)	3.17×10^{-6} ***
Surface water	1 (1.4%)	70 (98.6%)	15.642 (3.245–281.561)	0.0074 **
Storage opening				
Narrow	70 (11.3%)	548 (88.7%)	1	
Wide	6 (6.9%)	81 (93.1)	2.22 (0.972–6.036)	0.0820
Household treatment				
Yes	1 (8.3%)	11 (91.7%)	1	
No	75 (10.2%)	618 (89.2%)	0.33 (0.018–1.848)	0.3027
When collected				
>Yesterday	10 (15.9%)	53 (84.1%)	1	
Yesterday	30 (10.8%)	247 (89.2%)	2.229 (0.936–5.029)	0.0593
>4 h	16 (10.7%)	134 (89.3%)	1.902 (0.747–4.696)	0.1668
<4 h	20 (9.3%)	195 (90.7%)	2.033 (0.818–4.85)	0.1152

Note: Hosmer and Lemeshow test, *p*-value = 0.934, showed that the model fitted well. Significance level codes: '***' 0.001, '**' 0.01, '*' 0.05.

Table 4. Multivariable analysis of factors associated with the presence of fecal coliform in household drinking water for the survey conducted during the dry season only (n = 341).

Variable	Fecal Contamination		AOR	*p*-Value
	Negative	Positive		
Storage last cleaned				
Today	19 (12.8%)	130 (87.2%)	1	
Yesterday	16 (13.6%)	102 (86.4%)	1.119 (0.494–2.592)	0.7887
<week	8 (18.2%)	36 (81.8%)	0.822 (0.296–2.425)	0.7131
>week	7 (23.3%)	23 (76.7%)	0.527 (0.172–1.715)	0.2699
How was storage cleaned				
Soap	23 (27.4%)	61 (72.6%)	1	
Grass/leaves	6 (5.2%)	109 (94.8%)	3.591 (1.312–11.036)	0.0170 *
Sand/rock	8 (11.4%)	62 (88.6%)	1.435 (0.534–4.073)	0.482
Water only	13 (18.1%)	59 (81.9%)	0.994 (0.408–2.44)	0.9886
Is toilet facility used				
Latrine	33 (22.4%)	114 (77.6%)	1	
Open defecation	17 (8.8%)	177 (91.2%)	1.673 (0.736–3.846)	0.2197
Socioeconomic classification (quintile)				
Q5	10 (35.7%)	18 (64.3%)	1	
Q4	16 (34.8%)	30 (65.2%)	0.856 (0.289–2.49)	0.7763
Q3	12 (13.8%)	75 (86.2%)	2.425 (0.783–7.597)	0.1239
Q2	5 (4.7%)	101 (95.3%)	5.984 (1.602–24.941)	0.0098 **
Q1	7 (9.5%)	67 (90.5%)	2.193 (0.578–8.736)	0.2535

Note: Hosmer and Lemeshow test, *p*-value = 0.967, showed that the model fitted well. Significance level codes: '**' 0.01, '*' 0.05.

4. Discussion

4.1. Household Survey

The water supply service ladder finding in this study suggests that the community's water services were significantly lagging behind the goal of achieving universal access to safely managed water supply in 2030, as outlined in SDG 6. A significant proportion of households (41.9%) relying on unimproved sources and 8.3% on surface water highlights the need for urgent measures to improve and expand access to safe and reliable drinking water. The study conducted in the central and North Gondar zones reported only 23% had basic water supply services [32], which is lower than the finding of this study (39.2% of them basic and 0.3% of them safely managed water services ladder). Another study in the rural Amhara region revealed that 65.1% of surveyed households were using improved water sources, and 16.3% were using surface water [33], which was greater than our study. This study found that only 25.8% of households spent more than 30 min collecting water. This is notably lower than the findings of other studies, which reported that over 70% of households experienced such lengthy water collection times [32–34]. The study in the Fogera and Mecha districts reported that 34% of households spent more than 30 min [35]. However, the finding that 18% of surveyed households spent more than 30 min collecting water [36] was lower than our findings. A considerable number of households in the study area have to collect water from sources outside their yards, which could result in increased effort and time required to obtain water. This could particularly affect women and children, who are often responsible for fetching water, by reducing their time allocation for study and income generation. Therefore, it is crucial to enhance access to water sources closer to households in order to lessen the burden of water collection and increase overall water availability.

Our survey found that 84.3% of households had safe water storage, 88.1% used the pouring method to withdraw water, and 96% had covered their storage containers. In the rural Amhara region, 89.8% had lids for their storage, and 60% practiced pouring techniques to withdraw water [33]. The study conducted in the Farta district [34] found that 64.9% of households used the pouring method, which is lower than our study finding. However, their finding showing that 97.8% of households have a storage container with a lid is consistent with our study. The study conducted in the Boloso Sore district [36] indicated that 90.5% of households practice the pouring method, which is consistent with this study's result. Another study in northwest Ethiopia revealed that 87.9% of households use storage with a closing lid, 64.5% use the pouring technique, and only 37% practice safe storage [32], lower than the findings of our study. It is important to raise awareness and promote safe water handling practices to reduce the risk of recontamination in households. Tap dispensing methods can improve the safety and convenience of water storage use, and their low usage suggests a need for further investigation into barriers to their adoption and potential solutions.

This study revealed that only 2% of households practice household water treatment, which is much lower than the findings of [32,34], which reported more than 15% of surveyed households practice household water treatment. The study conducted in the rural Amhara region reported about 8% of households were practicing household water treatment [33,35]. Income of the household, education level, contact with household water treatment promotion activities, and type of water sources used are among the factors influencing the practice of household water treatment [37]. It is important to raise awareness about the importance of water treatment and to promote the use of effective treatment methods to ensure safe drinking water for all households. About 42.2% of households were able to clean their storage before collecting water, which is much lower than other previous studies [36,38].

The prevalence of open defecation among the surveyed households was approximately 57.2%. The study in the Farta district reported a lower percentage (42.7%) of open defecation [38]. In the flood-prone area of the South Gondar zone, the prevalence of open defecation was significantly higher, with 94.7% of households practicing it [24]. The study conducted in the Fogera and Mecha districts reported a consistent finding with our study in terms of percentage of households practicing open defecation [35]. Of the pit latrine user's households, 69.7% were using open pits, which is lower than the result reported in the Farta district [38]. The finding that only 9.4% of households practice at least basic sanitation services indicates a need for efforts to promote the construction and use of improved sanitation services.

4.2. Microbial Quality of Drinking Water

The multivariable logistic regression analysis revealed that the season of the year, the water source of households, the storage cleaning method, and the socioeconomic group of the household were significant predictors of fecal contamination in the household drinking water. The analysis indicated that during the dry season, households using soap to clean their storage, those using improved water sources, and high-income households had significantly lower FC loads in their storage water. Nevertheless, the Chi-squared test revealed the statistical significance of additional factors. The test indicated that households located in the Dera district, households practicing water treatment techniques, households using a latrine, and households using a pit latrine equipped with a slab had significantly low FC load. It is worth noting that the additional factors identified through the Chi-squared test were primarily associated with the health risk category rather than solely relying on the presence of FC.

Overall, only 11% of households were able to drink water free from FC, which indicates fecal contamination was prevalent in the households drinking water; hence, public health is under threat. The study conducted in the Farta district reported that all samples were positive for FC detection [39]. In the Boloso Sore district [36] and in the rural areas of Nepal [37], only 9% of households had water free from FC, which is consistent with our study. The study conducted in the flood-prone area of the South Gondar zone reported that about 37.8% of the samples tested negative for FC detection [24], and another study in the

North Gondar zone reported that 27.4% of household storage had no FC, and about 32.4% fell into high-health-risk category [40]. Similarly, a study conducted in Bangladesh reported that 16.2% of household samples showed no presence of *E. coli* [12]. The aforementioned studies indicate a lower level of contamination compared to the findings of this study. In this study, there was a 1.8-fold increase in the likelihood of fecal-contaminated household drinking water during the wet season compared to the dry season. In a study conducted in rural India, 31% of household samples were free from FC, with severe contamination observed during the wet season [41].

Water collected from improved sources showed a higher proportion of samples with no FC than unimproved sources. Unimproved water source users had a 3.7-fold higher likelihood of fecal contamination, while surface water users had a 15.6-fold higher likelihood compared to users of improved water sources. Similar findings regarding the dependence of stored water quality on its source have been reported in other studies [35,42]. Likewise, the study conducted in India found that households utilizing river water had higher concentrations of FC compared to those using river bank water and osmosis-filtered water [41]. Households using unimproved sources had higher loads of fecal contamination compared to those using improved water sources [40]. Fecal contamination was significantly lower in piped water supply compared to wells and springs [43]. Thus, the provision of improved water sources reduces the risk of fecal contamination and subsequently minimizes the threat to public health. However, it is noteworthy that a significant proportion of community water sources were contaminated with fecal matter in the Farta district [44].

In this study, an increase in FC load from the source to household storage was observed, although not statistically significant. Contamination at the point of use can arise from various factors, such as the quality of the source water, inadequate storage practices, or unhygienic behaviors of the users [42]. An increase in FC concentration from the source to the storage container was also reported in other studies [37,45]. The study conducted in slum areas of Hawasa city demonstrated a significant increase in FC contamination, with levels rising from 6.7% in tap water to 31.6% in household storage [13]. Our study findings indicated that safe storage practices were associated with lower levels of FC concentration compared to unsafe storage methods, which contributed to additional contamination within the household. The discrepancy may be due to improper dipping bowl placement and contact with unhygienic fingers during the dipping process. Households practicing unsafe storage were found significantly contaminated with fecal matter in the study conducted in Panama [46]. The study in rural India also showed households using the dipping method had a higher level of FC contamination compared to tap users [41]. The result implies the need to deal with water quality beyond the sources at the household level.

The use of grass/leaves for cleaning water storage resulted in a 3.6-fold higher likelihood of fecal contamination compared to households using soap. These findings highlight the significant impact of the cleaning method on the contamination of drinking water. Washing the storage containers with soap was associated with significantly lower levels of fecal contamination compared to other cleaning techniques. This is because soap has properties that can effectively remove dirt, bacteria, and other contaminants from surfaces. Furthermore, it was observed that water stored for longer periods exhibited relatively lower FC loads. This can be attributed to the extended storage, allowing for the natural reduction of FC concentration. Our findings also suggest that practicing household water treatment can reduce the FC load in the water. However, it is worth noting that a substantial portion of the treated water samples still exhibited high loads of FC. This could be attributed to inadequate implementation of the treatment methods or the use of inefficient treatment techniques. The study in Myanmar showed that household water treatment methods, such as ceramic purifiers and reverse osmosis devices, were found to be effective in removing FC [47]. Hence, we suggest adopting effective household water treatment techniques to decrease fecal contamination in drinking water.

Households using latrines had lower FC loads compared to households practicing open defecation. This suggests that deteriorating sanitation conditions are associated with compromised water quality. Similar findings have been reported in other studies, where households using latrines had lower FC loads compared to those practicing open defecation [24,35,41]. The study conducted in the peri-urban area of Lusaka demonstrated that the presence of roofed pit latrines significantly decreased the concentration of FC in household drinking water, attributed to the lower fly density associated with roofed latrines [48]. Practicing improved sanitation, including the use of latrines and appropriate sanitation facilities, is crucial for maintaining safe drinking water and reducing the risk of waterborne diseases associated with fecal contamination. These findings underscore the need for comprehensive strategies and interventions to promote improved sanitation practices and ensure access to safe drinking water for all households.

Low- and middle-income households stored water were found to have a 5.98-fold higher likelihood of fecal contamination compared to the high-income households stored water. Similar results were obtained from a study conducted in the North Gondar zone [40]. Likewise, the study conducted in low- and middle-income countries demonstrated a significant difference in FC load between high- and low-income households [15]. The observed difference in FC concentration among socioeconomic groups can be attributed to two reasons. Firstly, the high-income households predominantly relied on piped water supply, which typically provides better quality water and reduces the risk of contamination. In contrast, low-income households heavily rely on unprotected springs as their water source, which are more susceptible to contamination and pose a higher risk to water quality. Secondly, there were disparities in sanitation practices between the socioeconomic groups. The low-income households were more likely to practice open defecation or use open pits, which increases the likelihood of fecal contamination and contributes to extremely poor water quality. On the other hand, the high-income households primarily used pit latrines with slabs, which provide an improved means of disposing of human excreta and mitigate the risk of contamination. According to a study conducted in low- and middle-income countries, it was found that the bottom three quintiles of wealth had the lowest access to piped water and improved sanitation facilities [49]. Income inequality acts as a barrier to the adoption and implementation of WASH (water, sanitation, and hygiene) facilities, emphasizing the importance of financial inclusion as a key solution [50]. Improving access to safe drinking water and promoting proper sanitation practices are essential steps in reducing fecal contamination and enhancing overall public health. Efforts should be made to provide equitable access to clean water sources, especially in disadvantaged communities relying on vulnerable water sources like unprotected springs. Additionally, promoting and supporting improved sanitation facilities can contribute to reducing fecal contamination and improving water quality in all socioeconomic groups. Overall, the study recommends the need for continuous public awareness to improve drinking water quality and give priority to public health by all stakeholders.

5. Conclusions

This study involved surveying and collecting water samples from 720 households in the Dera and Farta districts during the wet and dry seasons. Water and sanitation service level, FC and free chlorine residual test at household drinking water storage, and determinant factors associated with FC presence were the focus of this study. Among the households surveyed, it was found that only around four out of ten households had access to basic water supply services, while approximately six out of ten households were practicing open defecation. These findings indicate that the study area is significantly lagging behind the goal of achieving universal access to safely managed water supply and sanitation for all by 2030, as outlined in SDG 6. Only approximately one out of ten households had access to drinking water free from FC contamination, and free chlorine residual was not detected in any of the surveyed households. Fecal contamination was widespread throughout the year, with an exacerbation during the wet season. Consequently, the health of the consumers faced significant threats. The season of the year, type of water sources, methods of storage cleaning, and socioeconomic of the households were identified as predictors of fecal contamination in the household drinking water. Water collected from improved water sources demonstrated better quality in comparison to other sources. Households that washed their storage containers using soap showed relatively lower concentrations of FC compared to households using alternative methods. Increasing access to improved water sources and promoting the use of soap during container washing can effectively reduce fecal contamination in household drinking water. The analysis of socioeconomic status indicated that high-income households had lower levels of FC contamination compared to low-income households. It emphasizes the importance of making efforts to ensure equitable access to safe drinking water for all individuals, regardless of their socioeconomic status. Based on the findings of the study, collaborative efforts of the government, development partners, concerned parties, and the community are necessary as soon as possible to reduce the public health risk due to fecal-contaminated drinking water.

Based on the findings of this study, several future research directions can be proposed to expand on the results and address the identified challenges. The study indicated that adequate household water treatment practices were observed in only a small number of households. Future research should focus on the factors that hinder or promote household water treatment in the study area. Additionally, we recommend conducting further studies on sanitation practices in the area, as these are directly related to drinking water quality.

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