International Journal of Hygiene & Environmental Health, Vol.208(3), 13 May 2005, pp.153-161

"Mechanisms leading to post-supply water quality deterioration in rural Honduran communities"

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Abstract

Drinking-water can become contaminated following its collection from communal sources such as wells and tap-stands, as well as during its storage in the home. However, the mechanisms leading to contamination between the points of supply and consumption have not been well documented. This study carried out field-based experiments in three rural Honduran communities to investigate the potential for contamination through hand contact, method used to draw water, and dirty collection containers. The possibility of bacterial growth occurring in stored water was also considered. Hand – water contact was observed frequently during the collection and drawing of drinking water. Faecal contamination was present on 44% of women's fingertips tested during normal household activities, and this faecal material was easily transferred to water. An immediate deterioration in water quality was observed on filling collection containers. Faecal material was detected on cups and beakers used for drawing stored drinking-water. Evidence was produced indicating that thermotolerant coliforms remain attached to the inner surface of clay storage containers after rinsing. Drinking-water quality deteriorates during collection and storage as a result of multiple factors linked to hygiene practices and circumstances. However, hands have the greatest potential to introduce contamination because of the constant risk of contact during household water management.

Key Words: contamination; drinking-water; deterioration; hands; hygiene; storage

Introduction

In a previous paper evidence was presented to demonstrate that water quality deterioration occurs regularly between collection from a communal water point and during storage in the home (Trevett et al, 2004). Approximately 81% of borehole samples were recorded as exhibiting between zero and 10 thermotolerant coliforms/100ml (hereafter reported as colony forming units - cfu/100ml), while only 29% of samples from household stored water were recorded in this range, and 20% exceeded 1,000 cfu/100ml.

Most literature on the subject of water quality deterioration either offers no explanation for the cause (Rajasekaran et al, 1977; Han et al, 1989; Morin et al, 1990; Simango et al, 1992; Genthe et al, 1997), or suggests that it results from poor water handling without substantiating this assertion (Shiffman et al, 1978; El Attar et al, 1982; Khairy et al, 1982; Heinanen et al, 1988; Blum et al, 1990; Verweij et al, 1991). Other studies have concentrated more on how to prevent water quality deterioration through the introduction of improved collection and/or storage containers (Deb et al, 1986; Empereuur-Bissonnet et al, 1992; Mintz et al, 1995; Roberts et al, 2001).

Generally, post-supply water quality deterioration has been assumed to result from contamination through contact with hands or utensils used in domestic water management. Another possibility that has rarely been considered is that bacterial growth is involved in water quality deterioration (Roberts et al, 2001). This paper documents the results of a study aimed at identifying the principal mechanisms leading to water quality deterioration in rural Honduran communities.

Study design

A conceptual framework was developed, based on observed water management practices (Trevett et al, 2004). This included all conceivable water quality deterioration factors (Figure 1). Three of the deterioration factors (airborne, insects, animals) were excluded from this study, as they were beyond the available resources.

A series of field-based experiments and an observational study were designed to investigate 5 of these factors (hands, dipping utensils, collection and storage containers, and bacterial growth). The objectives of the study are summarised as follows:

- Learn whether faecal material was commonly present on women's fingertips, and if so, whether it could be readily transferred to water
- Investigate whether faecal material was routinely present on utensils (dipping utensils) used to draw stored drinking-water
- Determine whether deterioration begins at the collection stage
- Determine whether the introduction of a ladle to draw drinking-water, would lead to lower colony counts in stored water quality
- Test the hypothesis that bacterial growth might occur in clay containers used for storing drinking-water
- Quantify the number of thermotolerant coliforms that remain attached to the internal surfaces of clay *tinajas* after rinsing with clean water
- Quantify the frequency of hand contact with stored drinking-water, and evaluate the hygienic management of drinking-water in the home

Field research was carried out between March and December 2000 in the same three rural communities in southern Honduras, in which significant water quality deterioration was reported (Trevett et al, 2004). Study communities were dependent for their drinking-water needs on one or more community wells equipped with simple hand pumps. Villagers collect water on a daily basis using a variety of containers including plastic and metal buckets, plastic bowls and jerrycans that are typically of between 15 and 20 litres capacity.

A complementary laboratory-based study was also planned to provide additional data through research in a controlled environment. This study was carried out by Janin (2000), with guidance and input from the authors of the present paper.

Methodology

Households were mostly selected from those already known through previous research. Non-random selection was justified on the grounds that water quality deterioration had already been observed in these households. Furthermore, a measure of trust had been established which was considered important because the research would be intrusive.

Water samples were processed using membrane filtration and incubated on membrane lauryl sulphate broth at 44°C ± 0.5°C for 18 – 24 hours in accordance with Department of the Environment guidelines (1983). A portable laboratory using membrane filtration enabled samples to be processed on site, (Oxfam-DelAgua water testing kit, Robens Centre for Public and Environmental Health, University of Surrey, UK), and within 6 hours of sampling. As a control measure, 100ml volumes of sterilised distilled water were processed to ensure that the equipment was being adequately sanitized between samples.

Analysis of variance was used to test the statistical significance of data collected from two of the experiments. All statistical analysis was carried out using Minitab (Release 13.1 ©2000, Minitab Inc.). The individual experiments and their methodologies are summarised as follows:

Contamination experiments

1. Fingertip testing

The women's activities immediately prior to fingertip testing were noted. Samples were obtained from the fingertips of 32 women from 23 households. Women were asked to dip their fingers up to the first joint into sterilised distilled water. Contact time was estimated at between two and three seconds. Samples were then analysed using membrane filtration.

2. Dipping utensil experiment

A total of 30 utensils (cups, beakers, gourds) made of plastic, glass or natural material were tested from 30 households. The procedure involved wiping a dry, new cotton bud around the inside lip of the utensil three times. The tip of the cotton bud was cut off and caught in a sterile steel cup containing 25ml of sterilised distilled water. The distilled water was gently agitated for 30 seconds before membrane filtration.

3. Collection container experiment

This was achieved by testing water quality immediately after the container had been filled, and through careful observation of water collection practices. Samples were taken at random from 26 collection containers including plastic and metal buckets, jerry cans, and one plastic cántaro (a traditional container). The procedure involved testing 10ml samples drawn immediately after the collection container had been filled. Samples were processed using membrane filtration.

4. Ladle experiment

Six ladles were distributed to households in the community with a borehole supply. Women were asked to serve drinking-water using the ladle and keep it permanently in the storage container. Stored water quality in new ladle-using households was tested on 4 non-consecutive days.

Bacterial growth experiments

1. Bacterial growth in stored water

If nutrients are present in a biofilm on the internal surfaces of clay containers, it may be possible for coliform growth to take place. This hypothesis was tested by analysing samples at regular intervals from a clay tinaja taken out of normal use for the duration of the experiment.

Existing water in the tinaja was replaced with approximately 15 litres of fresh well water. Two samples from the tinaja were immediately tested. Thereafter, two samples were taken every three hours until the water had been stored for a total of 27 hours. Samples were processed using membrane filtration as described above. The experiment tested two containers from a community with a hand dug well, and two containers from the community with the borehole.

2. Thermotolerant coliform attachment in clay water storage containers

The experiment was carried out in 4 households in the community with a borehole water supply. The tinaja was emptied and then rinsed with approximately 4 litres of bottled drinking-water. This was to ensure that the analysis would test for thermotolerant coliforms attached to the clay wall as opposed to stored water in the tinaja. A sterilised aluminium petri lid was used to scrape the internal clay wall or base. The length of the scraping was estimated at between 15 and 25 cm, and was repeated 3 to 5 times. It was then rinsed with approximately 100 ml of distilled water, which drained into a sterilised sampling cup. However, only 50 ml of the rinsing water was processed to avoid covering the membrane with any sediment resulting from the scraping. After scraping, the scratch marks were clearly visible and it can be estimated that the contact width was approximately 0.3 cm. It is therefore possible to roughly estimate the surface area scraped in each tinaja, and thus an approximate colony count per container.

Water use and hygiene observation study

A female Honduran research assistant was contracted on the grounds that a woman and native Spanish speaker should be able to achieve a greater degree of confidence with the women householders than a foreign male researcher. A simple questionnaire was used as a premise to carry out observation for approximately one hour in each of the 36 households included in the study. Nevertheless, the questionnaire provided useful information on socio-economic status, personal hygiene, water use, sanitation and health.

Results

Contamination

Both the fingertip experiment and direct observation indicate the strong possibility that direct contamination via hand contact is involved in water quality deterioration. Table 1 shows that nearly half (44%) of the women's fingertips tested for contamination with faecal material were positive. Although the mean level of faecal contamination is relatively low, it is significant that this was achieved with a single brief contact.

Finger contact with drinking-water happened on more than half (56%) of the observed water-drawing events. Only family members were seen to draw water, though this includes the extended family. A high proportion (47%) of children were observed to draw water for themselves, some as young as 2 years old.

Results from the dipping utensil experiment demonstrate that these utensils can be contaminated with faecal material (Table 2). In general householders do not assign a specific utensil to draw water (excepting ladles), neither is any distinction made between utensils for dipping or drinking.

Results from the collection container experiment clearly suggest that water quality deterioration begins at the moment of collection. Samples from the borehole were, with one exception, always less than 10 cfu/100ml. In contrast, water quality in the collection containers varied greatly, and around one fifth of samples exceeded mean borehole water quality by two orders of magnitude. Table 3 shows the mean water quality at the borehole and in each type of collection container. The difference between borehole and overall collection container water quality is not statistically significant (probability 0.25). However, the difference between water quality in plastic buckets and the borehole is highly significant (probability 0.03). The lack of overall significance could be explained by uncharacteristic results on the first day's analysis, which recorded an unusually poor borehole water quality (37 cfu/100ml) and zero results for all collection containers. If the first day's data were to be excluded from the analysis, the difference between borehole and collection container water quality would show statistical significance (probability 0.03).

It was observed that collection containers were usually rinsed before filling. In the case of buckets a hand was often rubbed around the inside while rinsing. Hand – water contact was frequently observed as excess water was scooped out, as containers were moved from under the pump, and when they were lifted on to the head. Buckets were the most common type of collection container observed during the experiment (77%), followed by jerry cans (19%). None of the buckets from which samples were taken had lids, while all but one of the jerry cans had lids and these were used.

The ladle experiment results (Table 2) were contrary to expectation, and did not lead to lower colony counts in stored drinking-water. In fact water quality was found to be significantly worse after the introduction of the ladle (probability 0.036). It is possible that households were using the ladle for other purposes as well as for drawing drinking-water.

Using data collected in the previous study (Trevett et al, 2004) a comparison was made of stored water quality by the method used to draw water from the storage container. Table 2 presents the results of this analysis and it can be seen that where drinking-water is poured it is of significantly better quality than in households where the ladle or dipping method is used.

Bacterial growth

Results from the bacterial growth experiment are presented in Figure 2. There is a general pattern of coliform die-off but with occasional increases over the 27-hour period. These increases might be the result of natural variation between sample replicates, rather than real bacterial growth. Mean water temperature in storage containers was 28°C which would be conducive to faecal bacterial growth assuming nutrients were available (Davis et al, 1980). The laboratory study recorded similar temporary increases in colony counts. It was also observed that survival times were longer in containers that had developed a biofilm on the internal surfaces (Janin, 2000).

Table 4 summarises the results from the thermotolerant coliform attachment experiment and shows that they were detected in three of the tinajas tested. The experiment demonstrates that a simple rinsing of the container allows small numbers of thermotolerant coliforms to remain attached to the internal surfaces. The laboratory study found somewhat higher numbers (4.4 to 7.3 cfu/cm^2) on the internal surfaces of clay containers but not on either plastic or metal containers. Furthermore, total bacteria counts from clay containers (5,000 bacteria/cm^2) were at least an order of magnitude higher than containers made of plastic or metal (Janin, 2000).

Observation and questionnaire

The questionnaire results are presented in Table 5. The majority (94%) of households ‘filter’ their drinking-water with a piece of linen-type cloth. The reason given for this practice was to filter out insects or dirt particles. However, it was also stated that only rarely was any such contaminant seen when filtering the water. No typical usage pattern was observed with respect to filter cloths. They were sometimes seen covering the drinking-water container, or hanging from a ceiling hook, or drying outside on the roof of the house. It did appear to be the case that these cloths were used exclusively for filtering water and had no other purpose.

Although the majority of households (67%) reported washing the container with water alone, it was also stated that a scrubbing brush or more often a piece of plastic sacking was used for cleaning. However, storage containers were not observed being cleaned.

Only two households reported that they boiled drinking-water but it was pointed out that this water was exclusively for infants of under one year. Chlorine disinfection was not practiced in any of the study households in spite of its availability and promotion by various agencies. The most common reason given for not using chlorine was the unpleasant taste.

Discussion

The overall picture that emerges from the study is that all the factors considered here could be involved in water quality deterioration. A set of interlinked, hygiene related practices and circumstances appear to be the basis for water quality deterioration. This study has not identified any one mechanism that can be described as the single root cause of deterioration. However, there remains a strong argument that hands have the greatest potential to introduce contamination because of the many opportunities where contact with drinking-water can and does occur. Observation confirmed that hand contact occurs during collection, transport and when dipping the stored drinking-water.

The fingertip experiment demonstrated that it is possible to introduce gross contamination with the briefest of contacts. It is significant that children draw drinking-water, as they will probably be less likely to avoid hand – water contact, and their hands may be expected to be more contaminated with faecal material than an adult's.

Our study clearly implicates dirty collection containers as a significant cause of contamination. Roberts et al (2001) suggest that buckets used for water collection become contaminated by hand contact. In their study in Malawi they observed that women often arrived at the well with their hand inside the bucket, and that before filling, the hand was rubbed around the inside of the bucket with a small quantity of water. Very similar collection practices were observed in Honduras. Furthermore, our results indicate that water quality collected in jerry cans was comparable to that of the borehole. This supports the premise that hands are the cause of the contamination because the narrow opening of the jerry cans does not permit hand entry. Roberts et al (2001) found that an "improved bucket" with an opening preventing hand entry greatly reduced faecal contamination of water at the time of collection. Feachem et al (1978) suggest that not washing hands when handling collection containers may lead to contamination.

The use of a cloth to filter drinking-water when it is transferred to a storage container was observed to be a common practice in the study communities in Honduras. In between uses there are clearly opportunities for the cloth to become contaminated from human, animal or environmental factors.

Once the water is in the storage container, there are several factors that may be involved in deterioration. There are several references in the literature that suggest that water quality deterioration may result from storage containers not being adequately washed (Feachem et al, 1978; Lindskog & Lindskog, 1988; Jagals et al, 1997; Ahmed et al, 1998; Hoque et al, 1999). Our thermotolerant coliform attachment experiment shows that small numbers [of thermotolerant coliforms] can remain attached to the internal surfaces of containers after rinsing. However, in their Bangladesh study, Ahmed et al (1998) found that the interior bases of water storage containers were heavily contaminated. Mertens et al (1990) comment in their Sri Lanka study that water stored in an earthenware container tended to be more contaminated than in metal or plastic containers.

Results of swabs taken from utensils used to draw water from the storage container indicate that contamination could take place when contact is made with stored water. The unexpected result of increased colony counts in households new to using a ladle is difficult to explain. However, what is clear is that stored water quality in households that pour their drinking-water is significantly better than in households that use either ladles or dipping utensils.

The results of the bacterial growth experiments in both the field and the laboratory are inconclusive. The general pattern is one of progressive die-off but with temporary increases in colony counts during the storage period. Pinfold observed bacterial growth in stored water used for dish washing in rural households in Thailand (1990). The mechanism of cross-contamination that he describes could transfer nutrients to stored drinking-water and facilitate growth..

Conclusion

Our research provides evidence to show that hands, dipping utensils, dirty collection containers, filter cloths, and the sanitary condition of storage containers can all play a role in water quality deterioration. Nevertheless, only hands are involved at every stage of domestic water management. Hands can directly contaminate stored drinking-water through contact, or indirectly through the transfer of faecal material to utensils used in household water management. The promotion of greater hygiene awareness surrounding domestic water management should receive more emphasis in community water supply programmes. Jerrycans appear to offer the most secure means of preserving water quality during collection. In terms of maintaining water quality during its use in the home, pouring water clearly has advantages over any practice which requires a utensil to be dipped into the storage container.

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FIGURES

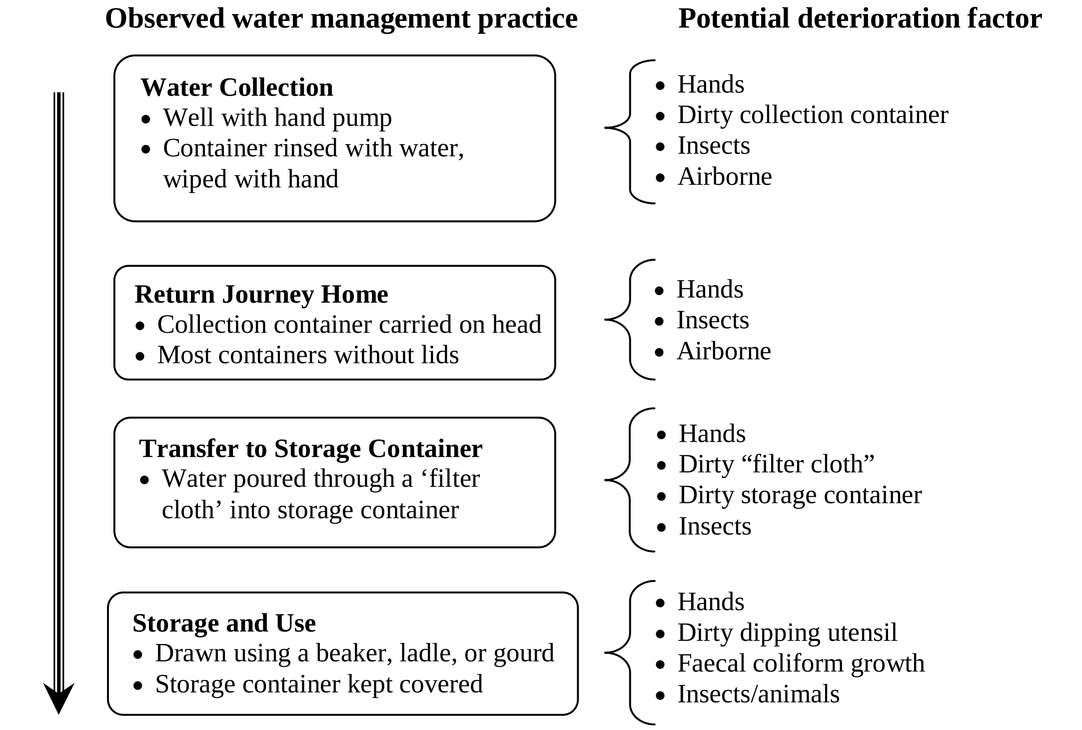

Figure 1: Conceptual framework showing the main characteristics of domestic water management, and the potential factors involved in water quality deterioration

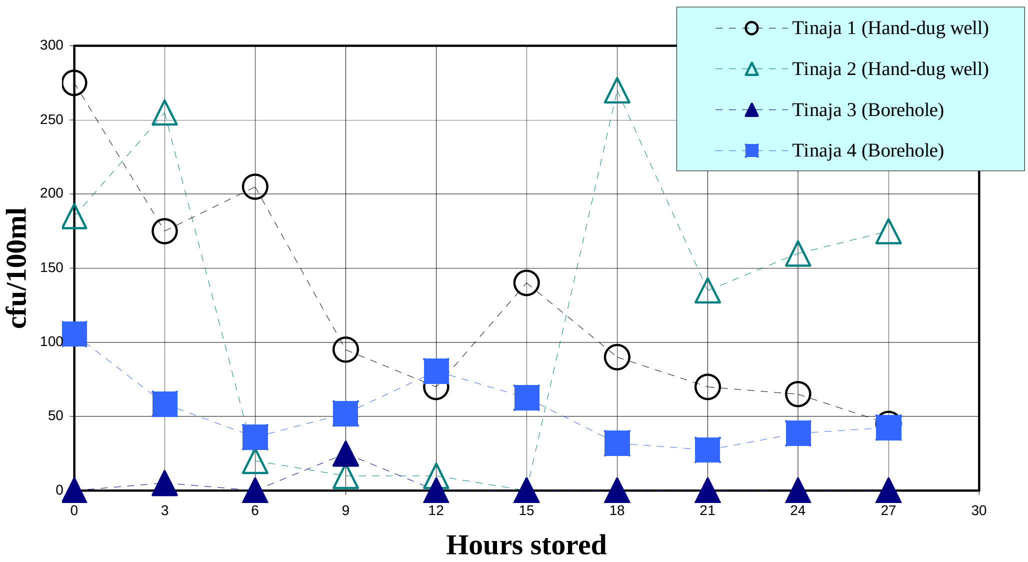

Figure 2: Stored water quality in household tinajas taken out of normal use to test the possibility that bacterial growth occurs during storage.

TABLES

Table 1: Faecal contamination of finger tips and observation of hand-water contact when drinking water is drawn from the storage container using a dipping utensil

	Result
Thermotolerant coliform counts obtained from fingertip samples from 32 women	
Number of positive samples (% of total)	14 (44%)
Geometric mean (range of positive samples)	9 cfu (1 to >2000 cfu)
Range of positive samples by order of magnitude (% of positive samples):	
1 to 10 cfu	9 (64%)
11 to 100 cfu	3 (22%)
101 and over cfu	2 (14%)
Observation of finger – drinking-water contact during dipping from storage container	
• No. of dipping events observed (number of households)	32 (20)
• No. of times contact observed (% of total observations)	18 (56%)
Who draws the drinking-water (32 observed occasions):	
• Housewife (% of total observations)	13 (41%)
• Children (% of total observations)	15 (47%)
• Adult family member (% of total observations)	4 (12%)

Table 2: Faecal contamination of dipping utensils; and influence of method used to draw stored water on bacterial quality

Thermotolerant coliform counts obtained from swabs of 30 household utensils used to draw drinking-water from storage container		**Result**
Number of positive samples (% of total)		8 (27%)
Geometric mean (range of positive samples)		7 cfu (1 to 150 cfu)
Number of positive samples according to utensil type (total number of utensil)		Plastic cup: 1 (6) Plastic beaker: 6 (19) Glass beaker: 0 (2) Gourd: 1 (3)
Comparison of stored drinking-water quality[a] according to method used to draw water		**Probability**
Dip (cup or beaker)	86 cfu/100ml (74 samples)	0.12 (Dip versus ladle)
Ladle (existing users)	182 cfu/100ml (77 samples)	0.02 (Dip versus pour)
Pour	23 cfu/100ml (78 samples)	<0.001 (Ladle versus pour)
Stored drinking-water quality[a] before and after the introduction of a ladle for drawing water		**Probability**
Before	After	
81 cfu/100ml (60 samples)	292 cfu/100ml (32 samples)	0.036

a Geometric mean cfu/100ml

Table 3: Comparison of water quality in the borehole with water quality in collection containers immediately after filling

Description	**Borehole**	**All collection containers**	**Individual collection container type**			
			Plastic bucket	Metal bucket	Jerry can	Cántaro
Geometric mean cfu/100ml (number of samples)	4 (12)	11 (26)	26 (13)	11(7)	5 (5)	1710 (1)
Range of samples cfu/100ml	0 to 37	0 to >2000	0 to >2000	0 to >2000	0 to 20	N/a
Probability (collection container versus borehole water quality)		0.25	0.03	0.39	0.89	N/a
			0.08 all buckets			

Table 4: Colony counts obtained by scraping the internal surfaces of clay drinking-water storage containers (*tinajas*) after rinsing with clean water

Tinaja	Cfu		Area scraped cm^2 (estimated)		Wetted surface area (cm^2) / volume (*l*) of *tinaja* (est.)	Cfu per container (extrapolated)	Cfu/100ml (theoretical)
	1st sample	2nd sample	1st sample	2nd sample			
1	0	0	30	33	4,273 (28)	0	N/a
2	1	0	26	16	3,271 (19)	126	< 1
3	3	0	27	14	2,403 (12)	267	2
4	2	-	30	N/a	3,271 (19)	218	1

Table 5: Replies by the female head of household to the questionnaire survey of 36 households concerning domestic water management, hygiene and sanitation

No.	Water management, hygiene or sanitation question	Number of households (% of total survey households)
1	Households that assign containers to specific water uses within the household	34 (94%)
2	'Filter' drinking-water with a linen-type cloth when transferring collected water to storage container	33 (92%)
3	Method used to clean drinking-water storage container: • Water alone • Water and soap and/or bleach	 24 (67%) 12 (33%)
4	Frequency of washing drinking-water storage container: • Daily • Every two days • Every three days	 17 (47%) 15 (42%) 4 (11%)
5	Households that practice drinking-water treatment: • Boil drinking-water • Add chlorine	 2 (6%) 0
6	Method used to serve drinking-water: • Plastic or glass beakers • Ladle • Gourd • Plastic or glass cup with handle	 22 (61%) 7 (19%) 4 (11%) 3 (8%)
7	Households that have a latrine	20 (56%)
8	Households that raise animals inside the house	29 (81%)
9	Households where the female head of the household: • Completed primary education • Not received any formal schooling	 9 (25%) 16 (44%)
10	Households involved in subsistence agriculture	26 (72%)