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Domestic transmission routes of pathogens: the problem of in-house contamination of drinking water during storage in developing countries

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Summary Even if drinking water of poor rural communities is obtained from a 'safe' source, it can become contaminated during storage in the house. To investigate the relative importance of this domestic domain contamination, a 5-week intervention study was conducted. Sixty-seven households in Punjab, Pakistan, were provided with new water storage containers (pitchers): 33 received a traditional wide-necked pitcher normally used in the area and the remaining 34 households received a narrow-necked water storage pitcher, preventing direct hand contact with the water. Results showed that the domestic domain contamination with indicator bacteria is important only when the water source is relatively clean, i.e. contains less than 100 *Escherichia coli* per 100 ml of water. When the number of *E. coli* in the water source is above this value, interventions to prevent the domestic contamination would have a minor impact on water quality compared with public domain interventions. Although the bacteriological water quality improved, elimination of direct hand contact with the stored water inside the household could not prevent the occasional occurrence of extreme pollution of the drinking water at its source. This shows that extreme contamination values that are often thought to originate within the domestic domain have to be attributed to the public domain transmission, i.e. filling and washing of the water pitchers. This finding has implications for interventions that aim at the elimination of these extreme contaminations.

keywords drinking water storage, domestic contamination, *Escherichia coli*, water quality

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Introduction

The aim of drinking water projects is to provide a safe and sufficient supply of water to the consumer. In developing countries, this is often carried out by providing the consumers with access to a communal water source, such as a standpipe, in the close vicinity of the household or a water connection inside the household. However, in many parts of the world the water is provided only at certain time intervals during the day. Although connected to a supply system, the user still has to store water to have a sufficient amount of water available during the non-supply periods. Water storage is therefore a necessity both for those who are connected to a non-continuous water supply system and those who depend on drinking water sources located outside the household perimeter. Under hot climatic conditions, even households with a continuous water supply often store water in traditional clay pitchers, because of the cooling effect caused by evaporation through the porous clay.

The storage of water for hours or even days allows the possibility of faecal contamination of otherwise good-quality drinking water inside the household. Children may, in particular, cause contamination when they put their faecally contaminated hands or utensils into the household water container. This domestic pathway of pathogen contamination of the household drinking water is independent of pollution at the source. These two pathways for pathogen transmission have been described by Cairncross *et al.* (1996) as 'domestic domain' transmission corresponding to in-house contamination, and 'public domain' transmission that corresponds to pollution directly at the water source. While public domain microbiological contamination has been subject to numerous studies and to drinking-water quality guidelines for decades, contamination occurring within the domestic domain is often overlooked. However, to interrupt pathogen transmission, interventions are needed in both domains.

Since the work by Feachem *et al.* (1978), few studies have attempted to separate the microbial contamination of drinking water in the domestic and public domains in order to quantify their relative magnitude and the results from these studies were inconclusive. VanDerslice and Briscoe (1993) suggested that there is no additional health risk from the in-house (domestic) contamination, as this is merely a 'recycling' of already existing microorganisms inside the household to which the habitants have developed some level of immunity. Thus, they contend that contamination of the water source (public domain) is of greater health importance as new microorganisms in the source water can be introduced into the household. However, others have emphasized the importance of domestic contamination, especially during epidemics such as cholera outbreaks (Swerdlow *et al.* 1992). Several studies investigated the possibilities of reducing overall faecal contamination of drinking water (Mintz *et al.* 1995; Quick *et al.* 1996) and its possible health effects (Conroy *et al.* 1999; Quick *et al.* 1999).

This study was part of a 1-year observational study conducted by the International Water Management Institute (IWMI) on the impact of using irrigation water for domestic purposes in Pakistan (van der Hoek *et al.* 2001). In the observational study, we documented the importance of in-house contamination of drinking water, and in order to investigate this further, a 5-week intervention study was conducted. The objective was to determine whether a modified narrow-necked water pitcher could prevent domestic faecal contamination of drinking water. This paper presents results from both the larger observational study and from the more specific intervention study.

Materials and methods

Study area and drinking water sources

The study took place in the Hakra 6R irrigation scheme, located in the southern Punjab, Pakistan, close to the Indian border on the edge of the Cholistan (Thar) Desert. The area has very limited natural water resources and an extreme climate, with temperatures ranging from 2 °C in January to 48 °C in July with an average annual rainfall of 156 mm. The ground water in the Hakra 6R area is brackish and unsuitable for drinking or irrigation. The inhabitants are, therefore, totally dependent on irrigation canal water for all water uses.

All 94 villages in the area had similar types of drinking water sources. The main source was an open water tank located in the centre of the village, with a capacity of about 1050 m^3. The village tank was filled from an irrigation canal running parallel to the village boundary. Many households were connected via small polyvinyl chloride pipes inserted directly into the tank. A second drinking water source was open wells in the vicinity of most tanks, which supplied manually drawn seepage water. Other sources of seepage water, which is irrigation water seeping through the upper part of the soil and forming a small fresh water layer on top of the brackish groundwater, include water drawn from beneath the water tank, at the village boundary adjacent to the fields, or next to the canals. All the sources were, therefore, directly or indirectly connected to the irrigation water supply system and the initial quality of the irrigation water would, therefore, be expected to affect the quality of the different drinking water sources.

Data collection

For the observational study, 50 households in 10 randomly selected villages in the project area were selected representing the different drinking water sources used in the village. The 50 households were visited weekly for a year and water samples were taken from the clay drinking water pitcher found inside the household and from the original water source. The study was conducted from May 1998 to April 1999 and included the analysis of *Escherichia coli* in 1868 water samples. The presence of a piped water connection, water storage and toilet facility was registered for each household. Other aspects of the observational study, including comparison of faecal contamination levels in water sources and the corresponding in-house storage containers have been reported earlier (van der Hoek *et al.* 2001).

The poorest of the 10 villages was selected for the intervention study, as this village had no electricity and depended, unlike the other villages in the area, almost entirely on surface or open-well water. Thus, the only drinking water sources in the village were untreated surface or seepage water. From 129 households in the village, 67 were randomly selected. The drinking water sources used included the open village water tank, the open well located

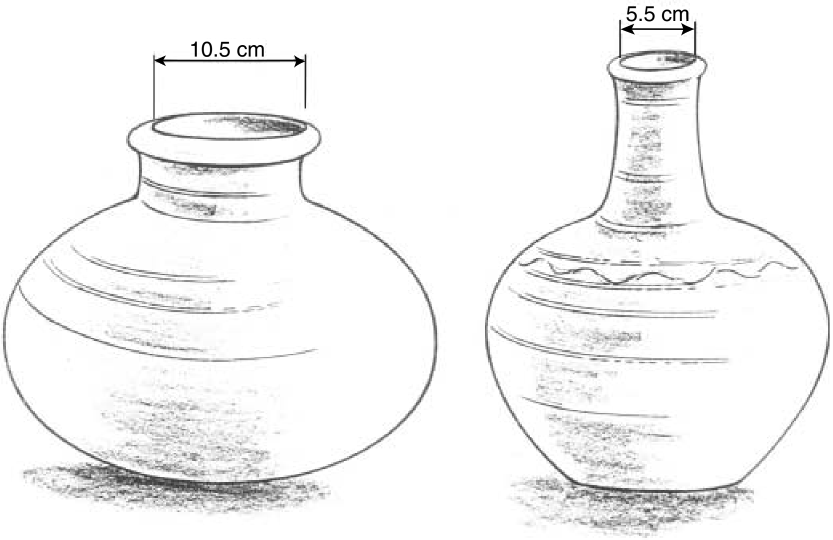

Figure 1 Traditional wide-necked and modified narrow-necked pitcher.

next to it and, of less importance, five separate seepage water sources each used by only one household. Thirty-four households were provided with a new narrow-necked pitcher and 33 households with a new traditional wide-necked pitcher (Figure 1). The pitchers were all made locally and the traditional pitcher was identical to those already used in the village. The only difference between the traditional and narrow-necked pitchers was the neck, whose internal diameter was reduced from 10.5 to 5.5 cm. The small diameter prevented people from using utensils or dipping hands to retrieve water from the pitcher, thereby reducing the risk of in-house contamination.

All except one of the selected households in the village agreed to participate in the intervention study and subsequently used the narrow-necked pitchers as their main water storage container for the entire study period. During the study two households dropped out, one because of breakage of the pitcher and the other because of migration.

For a period of 6 weeks in September and October 1999, two field workers visited the households every third day and collected a water sample from the pitcher and at the same time a sample from the source from which the water originated. For the source samples to reflect the actual source contamination at the time of water collection, the water samples were collected in the morning – just after most households had collected water. A total of 434 water samples were taken during the study period.

Bacteriological analysis

The number of *E. coli* in the samples was determined by membrane filtration using the commercial medium m-ColiBlue24® (Hach Company 1994), which allows simultaneous enumeration of total coliform and *E. coli* (Grant 1997). However, because of the potential problems of using total coliform counts as a faecal contaminant indicator in a tropical setting, only *E. coli* was enumerated and used as the indicator of the level of faecal contamination (Gleeson & Gray 1997). Water samples were collected, transported and analysed as described by Jensen *et al.* (2001). Presumptive *E. coli* colonies were enumerated and reported as numbers of colonies per 100-ml water sample.

Data analysis

The *E. coli* counts of the water source and in the pitcher were paired by date and household. For each pair, the number of *E. coli* in the source was subtracted from the *E. coli* number in the household sample on the same day. A positive value of more than 200 *E. coli* per 100 ml was defined as an extreme level of faecal pollution. The Wilcoxon signed rank test was used to compare the paired *E. coli* counts in source water and pitcher water. The results were analysed using the statistical software SPSS® version 8.0.

Results

Observational study

The differences between the paired values of *E. coli* counts found in the traditional household pitchers and the sources are plotted in Figure 2. The values are categorized by level of pollution at the source indicating the faecal

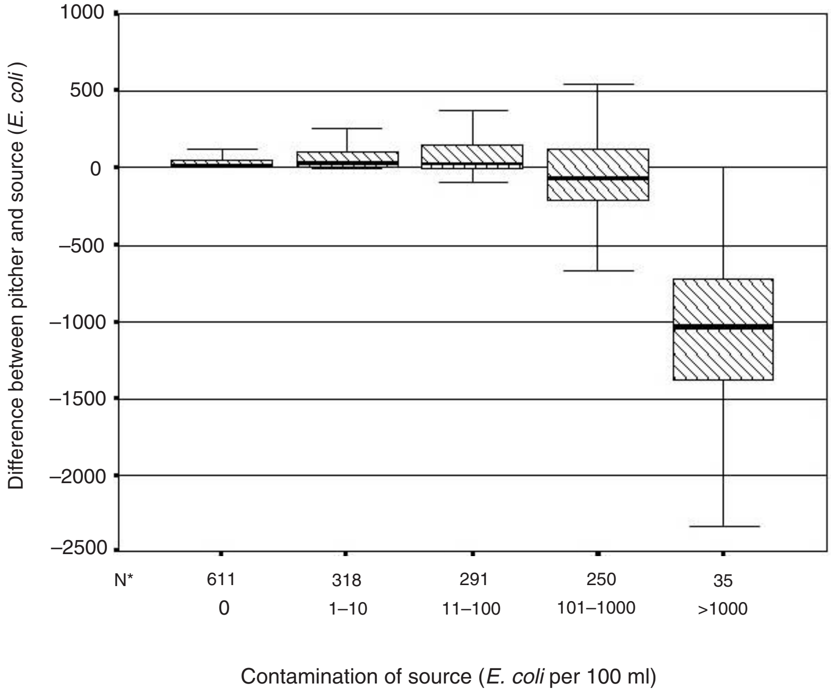

Figure 2 Box plot of the *Escherichia coli* level in household pitchers minus *E. coli* level in drinking water source. Positive values represent in-house contamination and negative values a bacterial die-off for the different source contamination levels. The box contains 50% of the values, with the median indicated as a horizontal line.

contamination in the public domain. A positive value indicates that the *E. coli* count found in the pitcher was higher than the number of *E. coli* found in the corresponding source water, suggesting either domestic domain contamination or bacterial growth inside the pitcher. A negative value suggests bacterial die-off in the pitcher. Figure 2 shows that a bacterial net die-off occurred when the *E. coli* numbers in the source were higher than 100 *E. coli* per 100 ml. When the source water contained up to 100 *E. coli* per 100 ml, it appeared that bacterial growth or domestic contamination occurred. These findings did not change after stratification of *E. coli* numbers by presence or absence of water connection or toilet facility for the different households (results not shown).

Intervention study

Water quality measurements of the two pitcher types were assigned a plus or minus rank depending on whether the value of the *E. coli* number in the pitcher minus the *E. coli* number in the corresponding source was positive or negative. A positive rank, therefore, suggests domestic domain faecal contamination and a negative rank indicates bacterial die-off within the household pitcher. Households using the traditional pitchers had a higher number of positive ranks than negative ranks, indicating in-house contamination, but the difference was not statistically significant (Wilcoxon signed rank test, $P = 0.484$). Households using the narrow-necked pitchers had a significantly higher number of negative ranks than positive ranks (Wilcoxon signed rank test, $P = 0.030$), suggesting reduced contamination occurring inside the pitcher.

The *E. coli* counts in water samples from the two pitcher types were categorized into those containing <100 or ≥100 *E. coli* colonies per 100 ml (Table 1). The narrow-necked pitchers had a greater proportion of samples that contained <100 *E. coli* per 100 ml than the traditional pitchers ($\chi^2 = 10.39$, $P = 0.001$). Water quality in the narrow-necked pitchers was significantly better

Table 1 *Escherichia coli* contamination levels in water samples from traditional and narrow-necked pitchers

Pitcher type	Number of samples <100 *E. coli* per 100 ml	Number of samples ≥100 *E. coli* per 100 ml
Narrow-necked	106	70
Traditional	72	96

than in the traditional pitchers, even when stratifying by level of faecal contamination (<100 or ≥100 *E. coli* per 100 ml) at the source (Mantel–Haenszel summary $\chi^2 = 7.60$, $P = 0.006$).

There was no difference between the two pitcher types in ability to avoid cases of extreme faecal pollution (≥200 additional *E. coli* colonies per 100 ml), as the traditional pitchers had 25 (12.3%) extreme cases from 195 paired values and the narrow-necked had 24 (13.0%) cases from 193 paired values.

Discussion

The intervention study showed that narrow-necked pitchers were to some extent capable of reducing the *E. coli* numbers in the stored water by minimizing the contamination within the household. However, in the observational study, water contamination with *E. coli* in the domestic domain was only measurable when the surface water contained <100 *E. coli* per 100 ml. Therefore, when the drinking water source is of relatively poor quality (i.e. above 100 *E. coli* per 100 ml) improved means of in-house water storage may not lead to measurably better water quality. Interventions to improve microbial water quality should then be targeted at the public domain. The results of the study also imply that even if the water supply meets the WHO (1993) quality guidelines of 0 *E. coli* per 100 ml, it does not necessarily mean that a correspondingly high water quality is maintained inside the household, unless the domestic domain faecal contamination is prevented.

Our intervention study was motivated by the outcome of the 1-year observational study that showed that water stored inside the household was often of a worse bacteriological quality than water from the source. The domestic faecal contamination was often of such a magnitude that the level of contamination at the water source seemed of minor importance. No significant difference could be found in the in-house *E. coli* numbers between polluted surface sources (geometric mean 102 ± 6 *E. coli* per 100 ml) and hand-pump-drawn seepage water (shallow groundwater), with very low or zero contamination levels (geometric mean 2 ± 4 *E. coli* per 100 ml) (van der Hoek *et al*. 2001).

In traditional household storage containers similar to the one used in the present study, continuous domestic faecal contamination and bacterial die-off can be expected. Faecal contamination in the domestic domain seems to be of greater importance to the overall contamination of the drinking water, when the water source is relatively clean. Our study shows that when the source water contains ≥100 *E. coli* per 100 ml, interventions to prevent domestic faecal contamination would have a minor effect on the microbial water quality as compared with interventions to prevent faecal contamination of the water source (Figure 2). Thus, interventions for the elimination of faecal contamination in the domestic domain will only have a significant effect if the water sources are relatively 'clean', e.g. containing <100 *E. coli* per 100 ml.

The reduction in the *E. coli* numbers in the narrow-necked pitcher is likely to be mainly the result of die-off because of the heat exposure in the pitcher (Barcina *et al.* 1986). The maximum air temperature during the observational study was 39 °C with a 24-h average of 31–33 °C during 6 weeks. At the end of the study period, we recorded pitcher water temperatures from 31 to 33 °C over a 24-h period with air temperatures from 32 to 46 °C, illustrating the 'cooling' effect of the pitchers. It was not possible to determine the actual retention time for the drinking water in the pitcher. In general, the pitchers were filled at least once every morning and the retention time until sampling could, therefore, be estimated to vary from 2 to 7 h.

The narrow-necked pitchers could not prevent the occurrence of extreme episodes of faecal contamination. As the neck diameter of the narrow-necked pitcher was believed to eliminate domestic domain contamination, this suggests that the extreme values originated in the public domain rather than the domestic domain. However, some narrow-necked pitchers had an initial high contamination level even when filled with clean source water. These extreme values could be attributed to contamination in the washing and filling process of the pitcher at the source or during transport.

As the clay pitchers were already used in the area for drinking water storage and important water-cooling purposes, no problems were recorded in the cultural acceptance of the narrow-necked pitchers. The only problem mentioned was the difficulty of cleaning the pitchers. Traditionally, the women in the area had been washing the inside of the pitchers with sand before filling them to remove the biofilm. However, discussions with the women suggested that by providing each pitcher with a brush (toilet type) this problem could be overcome.

Despite its inability to prevent occasional extreme faecal pollution, the narrow-necked pitcher had a positive effect on drinking water quality by reducing *E. coli* numbers. It is, therefore, proposed that future drinking water projects in developing countries should promote culturally acceptable in-house storage containers in order to reduce the domestic transmission of faecal–oral pathogens.

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