J HEALTH POPUL NUTR 2003 Mar;21(1):26-31
ISSN 1606-0997 $ 5.00+0.20

Effect of Chlorination of Drinking-water on Water Quality and Childhood Diarrhoea in a Village in Pakistan

Peter K. Jensen[1], Jeroen H.J. Ensink[2], Gayathri Jayasinghe[3], Wim van der Hoek[3], Sandy Cairncross[4], and Anders Dalsgaard[1]

[1]Department of Veterinary Microbiology, The Royal Veterinary and Agricultural University, Stigbøjlen 4, 1870 Frederiksberg C, Denmark; [2]International Water Management Institute, Km 12, Multan Road, Lahore 53700, Pakistan; [3]International Water Management Institute, PO Box 2075, Colombo, Sri Lanka; and [4]London School of Hygiene & Tropical Medicine, Keppel Street, London WC1E 7 HT, UK

ABSTRACT

To evaluate the importance of public-domain transmission of pathogens in drinking-water, an intervention study was carried out by chlorinating the public water-supply system in a village in Pakistan. The water quality improved and reached a geometric mean of 3 *Escherichia coli* per 100 mL at the last standpipe of the water-supply system. Drinking-water source used and the occurrence of diarrhoea were monitored on a weekly basis over a six-month period among 144 children aged less than five years in the village. In this group, the children using chlorinated water from the water-supply scheme had a higher risk of diarrhoea than children using groundwater sources, controlled for confounding by season and availability of a toilet and a water-storage facility. The incidence of diarrhoea in the village (7.3 episodes per 10^3 person-days) was not statistically different from that in a neighbouring village where most children used water from a non-chlorinated water-supply system with very poor water quality. In this study area, under non-epidemic conditions, the reduction of faecal bacteria in the public drinking-water supply by chlorination does not seem to be a priority intervention to reduce childhood diarrhoea. However, the study was of limited size and cannot provide conclusive evidence.

Key words: Drinking-water; Chlorination; *Escherichia coli*; Diarrhoea; Water quality; Pakistan

INTRODUCTION

The overall aim of drinking-water projects is to improve health status by providing pathogen-free drinking-water. The impact of drinking-water quality on the incidence of diarrhoeal disease and health status depends on the importance of transmission of pathogens via drinking-water, relative to transmission via other routes. Feachem categorized the water-related infectious diseases as water-washed or water-borne (1). The classification was later expanded into a unitary environmental classification of water- and excreta-related communicable diseases with seven categories (2). Cairncross *et al.* suggest that a distinction should also be made between transmission in two different physical domains: the public domain (outside the household) and the domestic domain (inside the household) (3). A desired health benefit would only be obtained if transmission of pathogens in both the domains is prevented.

The drinking-water supply sector has mostly targeted the water-borne transmission of pathogens. The most common method employed is the chlorination of drinking-water at treatment plants and in the distribution systems. Chlorination is considered essential to make it safe for drinking, especially when water is obtained from

Correspondence and reprint requests should be addressed to: Dr. Wim van der Hoek
International Water Management Institute
PO Box 2075, Colombo
Sri Lanka
E-mail: w.van-der-hoek@cgiar.org
Fax: +94-1-786854

surface-water sources. While there is universal acceptance and use of drinking-water chlorination in epidemic outbreak situations, there is an ongoing discussion on whether the interruption of water-borne transmission of pathogens reduces the occurrence of endemic diarrhoeal diseases in rural areas in developing countries (4-7). Most water-supply systems in Pakistan and other developing countries are not working according to design, and many are completely dysfunctional. This raises the question whether improvements in these schemes and provision of bacteriologically safe drinking-water would have an impact on the incidence of diarrhoeal disease. This study was done to examine the effect of chlorination of public-water sources on bacteriological water quality and endemic diarrhoea in a village in Pakistan.

MATERIALS AND METHODS

Study area

The intervention took place in a village (Village A) located in an irrigated area in southern Punjab, Pakistan. For comparison, water quality and incidence of diarrhoea were also monitored in a second village (Village B). The two villages were almost identical with respect to layout, ethnic composition, and socioeconomic status. They were situated 2 km apart and had separate water-supply schemes, both receiving raw water from the same irrigation canal. The irrigation canal was supplied with water from the Sutlej River, which received wastewater from the city of Lahore, located 250 km upstream from the two villages.

Both the water-supply schemes had a large sedimentation tank connected to slow sand-filters and a clear-water well, from which water was pumped to the village. The slow sand-filter in Village B was in a very poor condition due to lack of sand, and the filter could better be described as just a small retention tank. The slow sand-filter in Village A was in a somewhat better condition, although not functioning according to the original design because of non-optimal maintenance and growth of water plants on the filters. Accordingly, the initial water quality in the irrigation canal was expected to affect the water quality in both the water-supply systems. Both the systems provided water for about two hours early in the morning and for an hour in the afternoon. To overcome the non-supply hours, many households had installed a large concrete water-tank or a plastic drum for water storage. Nearly all households used traditional clay-pitchers inside the household perimeter for storage of drinking-water and cooling purposes. No families reported boiling or any other form of treatment of drinking-water before use. Not all households in the two villages used the water from the water-supply scheme. The alternative supply was shallow groundwater drawn by hand-pumps. Some families reported that they preferred the taste of groundwater. Others indicated that they were unable to pay the fees for the water-supply scheme (30 Pakistan Rupees=0.5 US$ per month).

Household selection

All households from the two villages that had children aged less than five years and that primarily obtained their drinking-water from the water-supply systems were selected for the study. This resulted in a study population of 82 children in Village A and 144 children in Village B. The majority of the selected households in both the villages regularly used groundwater for drinking instead of water from the water-supply system. This was mainly because of the high temperature of water in the drinking-water supply system (approximately 30 °C) in the summer months compared to a lower temperature (22 °C) of groundwater.

Chlorination

Water supply to Village A was selected for the intervention by chlorination because a chlorination pump (KOPKIT®,-030BAA) was present at the water-treatment plant. The village had a history of chlorination of the water-supply system. However, the pump operator had not been supported financially by the community and had, therefore, stopped chlorinating the water years ago. In community meetings that took place in December 1999, the people from Village A expressed their interest in, and support for, resumption of the chlorination of their water-supply system. The acceptance of the chlorination was high due to the perception that chlorination was '*pani dawai*,' meaning medicine for the water. To ensure a standardized disinfection, a field assistant from the study team was present at the pumping-station during daily supply hours to conduct the chlorination of water. The chlorination was done with calcium hypochlorite (30%) in powder form, which was mixed with water in dark plastic containers and immediately distributed in the system by a metering chlorination-pump to give a dose proportional to the water-flow. Before the onset of the study, the concentration of chlorine in the water was gradually increased from February to March 2000 so that the community gradually got used to the difference in the taste of water. The final concentration of chlorine during the study was 1.6 mg/L of free chlorine at the pump site, yielding a residual of 0.2-0.5 mg/L free chlorine at the last standpost (water-tap) in the distribution net. Levels of free chlorine were monitored with HANNA Instruments®, free chlorine test-kits.

Data collection

In February 2000, all the selected families were visited to explain the purpose of the study and seek their agreement to participate. All selected households agreed to participate, and the children received a unique identification number. From March to September 2000, two trained research assistants visited all the households on a weekly basis. The presence of a female research assistant made it possible to interview mothers of the children, even in households where *Purdah*, a system of female seclusion, was observed. The mothers of the selected children were asked on which particular days their children had suffered from diarrhoea in the previous week and which drinking-water sources were used. Diarrhoea was defined as three or more loose or watery stools or one bloody stool per day. A diarrhoea day was marked as a new episode if preceded by two days without diarrhoea (8). Data were recorded on pre-printed sheets. The methodology of household interviews had been tested in a previous epidemiological and water quality study conducted in the same area by the study team (9).

Water sampling and analysis for *Escherichia coli*

Pre-intervention water quality data were available for the two villages from two standpipes. At the start of the intervention, water samples for testing of faecal contamination were collected on a daily basis. However, the sampling frequency was changed later on to three times a week because of lack of supplies. Samples were collected from the sedimentation-tank, clear-water well, and the last standpost in the water-distribution system. The number of *E. coli* in the samples was determined by membrane-filtration using the commercial medium m-ColiBlue24® which allows simultaneous enumeration of total coliform and *E. coli* (10). However, due to 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. Water samples were collected, transported, and analyzed as previously described by Jensen *et al.* (11). *E. coli* colonies were enumerated and reported as numbers of colonies per 100 mL of water sample.

Data analysis

Incidence rates of diarrhoea, defined as the number of diarrhoea episodes divided by days of observation, were calculated for the selected children aged less than five years in both the villages. The sanitation and water storage status of individual households had been identified as important predictors of diarrhoea in a previous study in the same area (9). To control for confounding by these parameters, multivariate logistic regression was used. Because the previous study had shown that the effect estimates for sanitation and water storage only changed marginally when controlled for age, sex and socioeconomic status, the latter three parameters were not included in the analysis presented in this paper. A separate analysis was done for Village A comparing risk of diarrhoea among children using chlorinated water and children using non-chlorinated groundwater. To this effect, episodes of diarrhoea were related to the type of drinking-water that children were using at the time of the episode. As the choice of drinking-water source was very much determined by temperature and, therefore, season, calendar month was included as a potential confounding variable in this analysis. Data were analyzed using SPSS®, version 8.00.

RESULTS

Between July 1998 and May 1999, before the intervention, 23 water samples were taken from a standpost in Village A. Geometric mean of *E. coli* count was 13.3 per 100 mL, and 75% of the samples contained <155 *E. coli*/100 mL. In Village B, 30 samples were taken and these had a geometric mean value of 137.0 *E. coli* per 100 mL (with a 75 percentile of 462 *E. coli*/100 mL). Village B had a significantly higher mean *E. coli* count than Village A (Mann-Whitney Test, $p=0.001$). After chlorination, the water in Village A improved and was clearly less faecally-polluted than the water collected from the last standpipe in Village B. The water-supply system of the chlorinated village had a geometric mean of 3 *E. coli* per 100 mL with a 75 percentile of 3 *E. coli* per 100 mL. In Village B, the geometric mean was 49 *E. coli* per 100 mL with a 75 percentile of 319 *E. coli* per 100 mL. The figure shows the numbers of *E. coli* in the sedimentation-tanks and in the water from the last standpipes in both the villages. Water samples from the sedimentation-tank in Village A contained significantly less *E. coli* than water from the sedimentation-tank in Village B. It was not possible to identify the factor(s) responsible for this difference.

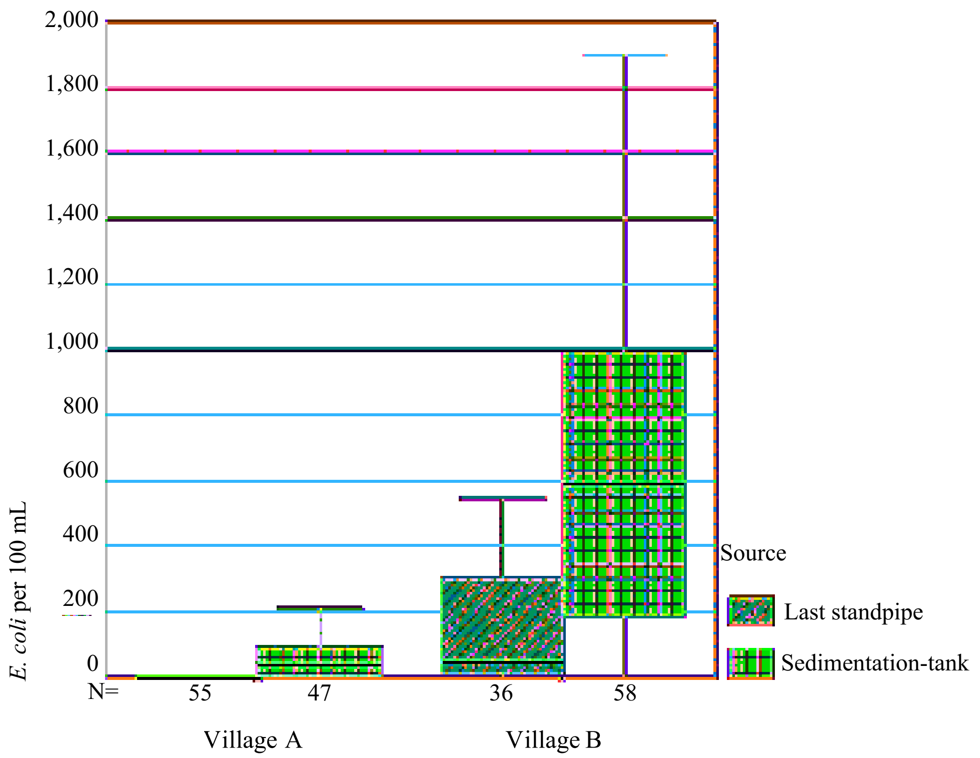
The joint effect of sedimentation, filtration, and chlorination clearly resulted in a much better water quality in Village A than in Village B, which only had inadequate sedimentation and filtration. However, even after chlorination, not all *E. coli* were eliminated from the water-supply system of Village A.

Despite the lower numbers of *E. coli* in the chlorinated village (Village A) than in Village B, it was not possible to detect a statistically significant difference in the occurrence of childhood diarrhoea between the two villages. In Village A, there were 106 episodes of diarrhoea for 14,513 person-days of observation (incidence rate 7.3 episodes per 10^3 person-days). In Village B, there were 157 episodes for 20,306 person-days of observation (7.7 episodes per 10^3 person-days). Within Village A, children using chlorinated water from the water-supply system had a significantly higher incidence of diarrhoea than children using groundwater (8.7 vs 3.6 episodes per 10^3 person-days, $p<0.001$). In the multivariate logistic regression analysis, children who reported an episode of diarrhoea were compared with children who did not report an episode of diarrhoea for exposure to chlorination, ownership of a toilet facility, and ownership of a water-storage tank. The incidence of diarrhoea was considerably higher in April and May than in other months. Season was, therefore, also included as a variable in the model. Chlorination, controlled for season and for differences in availability of toilet and water storage, was associated with a higher risk of diarrhoea in this analysis (odds ratio [OR] 1.99, 95% confidence interval [CI] 1.10-3.61).

DISCUSSION

Chlorination of drinking-water in the study village in Pakistan led to improvement of drinking-water quality to almost acceptable international standards. Despite this improvement in water quality, the incidence of diarrhoea was not lower than in a neighbouring village where drinking-water was not chlorinated and where water quality was very poor. Children switched drinking-water

Fig. Microbiological water quality measured as number of *E. coli* per 100 mL water in the sedimentation-tanks and at the last standpipe of the water-supply system in Village A (chlorinated water) and Village B (water not chlorinated). The thick line represents the median, the box represents the interquartile range, and the lines represent the range of the values



sources during the study period, and at times that they used other sources than the chlorinated water from the water-supply system, they had a lower risk of diarrhoea. The reason for this is not clear. The study could, therefore, not detect a positive effect of chlorination of the public drinking-water supply system on the incidence of childhood diarrhoea.

The lack of impact of chlorination on the incidence of diarrhoea in this study has to be interpreted with caution because the sample was of limited size. We did not control for confounding by socioeconomic status in the multivariate analysis. Because of the monthly fee, it is likely that households using water from the water-supply scheme were of a somewhat higher socioeconomic status than households using other sources. There are hierarchical interrelationships between variables, such as socioeconomic status, availability of a water storage facility, and presence of a toilet (12). In the present analysis, it is likely that control for confounding by storage and toilet facility also controlled for confounding by socioeconomic status. However, no inference can be drawn about the relative importance of these variables in explaining risk of diarrhoea. Our study faced the same methodological problems as other studies on the epidemiology of diarrhoeal diseases. There are at present no standard methods that can account for recurrent episodes of diarrhoea, that do not assume that the occurrence of diarrhoea in different time periods are independent events, and that do not assume that the occurrence of diarrhoea in one individual is independent of the occurrence of diarrhoea in another individual.

The general condition of the water-supply system in the chlorinated village (A) was better than in the non-chlorinated village (B), and clearly, the two villages were not comparable with respect to baseline water quality. Further, it is unknown whether residual chlorine was present in the water stored within the households in Village A. However, the importance of continuous and sufficient availability of water in reducing the occurrence of diarrhoea has been a consistent finding in our studies in Pakistan (9,13). It was also shown that contamination of relatively good-quality drinking-water could take place in the domestic domain, when the water is stored in clay-pitchers (14).

There have been a few epidemiological studies of the effect of chlorination of water-supply system on endemic diarrhoeal disease. Esrey *et al.* reported a 15% reduction in childhood diarrhoea in a review covering nine water projects with a range of a 0-90% reduction in diarrhoea (15). However, in a number of studies reviewed, the exposure groups were self-selected, introducing potential bias (5). In a more recent large multi-country review, the same author concluded that health benefits from improved water quality occurred only in households where sanitation was improved and when an optimal quantity of water was present (4).

High levels of *E. coli* contamination were found in the unchlorinated standpipe water in Village B, whereas in the chlorinated village (A), the contamination of faecal bacteria in standpipe water was minimal. It, therefore, seems that the incidence of diarrhoea in the two villages in the study area was not associated with levels of faecal contamination of the public drinking-water supply, at least at the prevailing contamination levels. Although it can be anticipated that the presence of *Campylobacter* spp., *Shigella* spp., and *Salmonella,* and other important bacterial pathogens in water is indicated by *E. coli*, the presence of other important causes of infectious diarrhoea, e.g. enteroviruses and protozoan parasites, may show a poor correlation with *E. coli*. It should also be noted that *Cryptosporidium parvum* and other protozoan parasites that are important causes of diarrhoea, show resistance to chlorine levels normally found in drinking-water.

If our finding of a lack of positive effect of chlorination of the public water-supply system on the incidence of childhood diarrhoea was confirmed in larger studies, it would question the almost mandatory chlorination of drinking-water in new water-supply schemes in developing countries. It is relevant to carefully assess whether chlorination of drinking-water in the public domain is a priority when a rural water-supply scheme is planned, especially if chlorination cannot be done reliably. Maybe, the provision of larger quantities of water would have a greater impact on diarrhoeal disease than has chlorination. If chlorination is planned, one should ask where the treatment would have the most impact on reducing human diarrhoea, at the public water-supply system or at household level (point-of-use treatment). Although we did not find a protective effect of chlorination of the public water supply, precautions need to be taken in epidemic outbreak situations—particularly so in areas where there is no existing tradition or few possibilities of boiling drinking-water, and especially with regard to pathogens causing epidemic disease, such as cholera (16), or when new pathogens are introduced to the water source against which the users do not have some sort of acquired immunity (17).

ACKNOWLEDGEMENTS

The authors would like to thank the staff at the International Water Management Institute field station, Haroonabad Pakistan, especially Nyla Tabassum, Tariq Mehmood, Tipu Naveed, Rizwan Aslam, Sarfraz Munir, Anjum Amin, and Najaf Balouch, for their efforts to collect and analyze samples and conduct interviews. Peter Jensen was supported by the Danish International Development Agency (DANIDA) and the Danish Council for Development Research (RUF, Grant no. 90936). Additional support for the project was obtained from the Canadian International Development Agency (CIDA).

REFERENCES

1. Feachem RG. Water supplies for low-income communities: resource allocation, planning and design for a crisis situation. *In*: Feachem RG, McGarry MG, Mara DD, editors. Water, wastes and health in hot climates. London: Wiley, 1977:75-95.
2. Mara DD, Feachem RG. Water- and excreta-related diseases: unitary environmental classification. *J Environ Engineer* 1999;125:334-9.
3. Cairncross S, Blumenthal U, Kolsky P, Moraes L, Tayeh A. The public and domestic domains in the transmission of disease. *Trop Med Int Health* 1996; 1:27-34.
4. Esrey SA. Water, waste, and well-being: a multicountry study. *Am J Epidemiol* 1996;143: 608-23.
5. Cairncross S, Kolsky P. Water, waste, and well-being: a multi country study (letter) *Am J Epidemiol* 1997;146:359-60.
6. VanDerslice J, Briscoe J. Environmental interventions in developing countries: interactions and their implications. *Am J Epidemiol* 1995;141: 135-44.
7. Moe CL, Sobsey MD, Samsa GP, Mesolo V. Bacterial indicators of risk of diarrhoeal disease from drinking-water in the Philippines. *Bull World Health Organ* 1991;69:305-17.
8. Morris SS, Cousens SN, Lanata CF, Kirkwood BR. Diarrhoea—defining the episode. *Int J Epidemiol* 1994;23:617-23.
9. van der Hoek W, Konradsen F, Ensink JHJ, Mudasser M, Jensen PK. Irrigation water as a source of drinking water: is safe use possible? *Trop Med Int Health* 2001;6:46-54.
10. Grant MA. A new membrane filtration medium for simultaneous detection and enumeration of *Escherichia coli* and total coliforms. *Appl Environ Microbiol* 1997;63:3526-30.
11. Jensen PK, Aalbæk B, Aslam R, Dalsgaard A. Specificity for field enumeration of *Eschericha coli* in tropical surface waters. *J Microbiol Methods* 2001;45:135-41.
12. Victora CG, Huttly SR, Fuchs SC, Olinto MTA. The role of conceptual frameworks in epidemiological analysis: a hierarchical approach. *Int J Epidemiol* 1997;26:224-7.
13. van der Hoek W, Feenstra SG, Konradsen F. Availability of irrigation water for domestic use in Pakistan: its impact on prevalence of diarrhoea and nutritional status of children. *J Health Popul Nutr* 2002;20:77-84.
14. Jensen PK, Ensink JHJ, Jayasinghe G, van der Hoek W, Cairncross S, Dalsgaard A. Domestic transmission routes of pathogens: the problem of in-house contamination of drinking water during storage in developing countries. *Trop Med Int Health* 2002;7:604-9.
15. Esrey SA, Feachem RG, Hughes JM. Interventions for the control of diarrhoeal diseases among young children: improving water supplies and excreta disposal facilities. *Bull World Health Organ* 1985; 63:757-72.
16. Swerdlow DL, Mintz ED, Rodriguez M, Tejada E, Ocampo C, Espejo L *et al.* Waterborne transmission of epidemic cholera in Trujillo, Peru: lessons for a continent at risk. *Lancet* 1992;340:28-33.
17. VanDerslice J, Briscoe J. All coliforms are not created equal: a comparison of the effects of water source and in-house contamination on infantile diarrheal disease. *Water Resources Res* 1993;29: 1983-95.