Water distribution system and diarrheal disease transmission: a case study in Uzbekistan

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Abstract. Deteriorating water treatment facilities and distribution systems pose a significant public health threat. particularly in republics of the former Soviet Union. Interventions to decrease the disease burden associated with these water systems range from upgrading distribution networks to installing reverse osmosis technology. To provide insight into this decision process, we conducted a randomized intervention study to provide epidemiologic data for water policy decisions in Nukus, Uzbekistan, where drinking water quality is suboptimal. We interviewed residents of 240 households, 120 with and 120 without access to municipal piped water. Residents of 62 households without piped water were trained to chlorinate their drinking water at home in a narrow-necked water container with a spout. All study subjects (1583 individuals) were monitored biweekly for self-reported diarrheal illness over a period of 9.5 weeks. The home chlorination intervention group had the lowest diarrheal rate (28.8/1,000 subjects/month) despite lack of access to piped water in their homes. Compared with the two groups that did not receive the intervention this rate was one-sixth that of the group with no piped water (179.2/1.000 subjects/month) and one-third that of the households with piped water (75.5/1.000 subjects/month). More than 30% of the households with piped water lacked detectable levels of chlorine residues in their drinking water, despite two-stage chlorination of the source water, and were at increased risk of diarrhea. Forty-two percent of these municipal users reported that water pressure had been intermittent within the previous two days. The dramatic reduction in diarrheal rates in the home-chlorination intervention group indicates that a large proportion of diarrheal diseases in Nukus are water-home. The home-chlorination group had less diarrhea than the group with piped water, implicating the distribution system as a source of disease transmission. Taken together, these epidemiologic data would support the hypothesis that diarrhea in the piped water group could be attributed to cross-contamination between the municipal water supply and sewer, due to leaky pipes and lack of water pressure. Relatively inexpensive steps, including chlorination, maintaining water pressure, and properly maintaining the distribution system, rather than reverse osmosis technology, should reduce diarrheal rates.

The quality of drinking water is closely associated with human health, and providing safe drinking water is a major public health priority. However, there are various methods of improving the quality of drinking water, and public health officials often must decide which methods are most appropriate for a given situation. We conducted a randomized intervention trial in Nukus, Uzbekistan to provide epidemiologic data to assist such a policy decision.

Nukus is located 250 km south of the Aral Sea, in one of the newly independent states of the Former Soviet Union. Poor water quality and water shortages pose a considerable public health threat to the 200,000 residents of Nukus, 20% of whom lack access to piped water. As a result of decades of extensive irrigation of cotton fields, water and land in Uzbekistan has become salinized and the availability of potable water has decreased. At the time of our study, the U.S. Agency for International Development had upgraded a two-stage chlorination system for the municipal water supply, but no disease monitoring had been conducted in Nukus to verify the effectiveness of this program.

The goal of our randomized intervention study was to determine water-home disease incidence through active surveillance. Intervention households lacking piped water were supplied with equipment for home-chlorination of drinking water. Self-reported incidence of diairhea was compared in both a group with and a group without access to piped water.

This approach allowed the identification of possible routes of disease transmission and enabled different options for water treatment to be prioritized, such as upgrading the existing water plant, improving management of the existing distribution system, revising the distribution system technology, or investing in reverse osmosis treatment options.

METHODS

In June 1996, scientists from the U.S. Centers for Disease Control and Prevention (CDC), in collaboration with local health officials, identified neighborhoods in Nukus that did not receive piped water from the municipal water supply. We constructed a detailed map of the six largest neighborhoods without piped water and estimated the number of houses. From these areas, we randomly selected 12 index homes, each of which would be part of a cluster of 10 households. Selection criteria required that a child less than five years of age lived in the house. The number of clusters in each neighborhood was assigned systematically proportional to the population. Because this project was a program evaluation and not human subjects research, IRB review was not required because the study did not fall under the human subjects regulations (45 CFR 46). Nevertheless, informed consent was obtained in the study. Trained interviewers began by interviewing an adult member at the index home; upon completion they turned left when leaving the house, skipped the next house, and proceeded until one adult member of each of 10 households had been successfully interviewed. The same sampling method was used to select another 12 clusters (of 10 households, each with a child) with piped water on the premises (Table 1). The index houses in the city were selected systematically, proportional to population from medical charts at the eight polyclinics serving Nukus, where all members of the population are registered.

TABLE 1: Selected demographic characteristics of participants by study group, Nukus, Uzbekistan, 1996*

	120 HHs with piped water 130 HHs with no intervention	120 HHs without piped water		Total population
		62 HHs with intervention	58 HHs with no miervennon	
Females	449	194	175	818

Males	399	203	163	765
Children <nve years old	176	88	80	344
Mean monthly income in US $ (range)	76 (0-750)	40 (0-150)	36 (0-5.000)	57 (0-5.000)
kg of meal or fish consumed by HH in last week (range)	3.7 (0.0-35.0)	1.6 (0.0-4.5)	1.6 (0.0-5.0)	2.6 (0.0-35.0)
Use of taxi by interviewee last month (range)	2.1 (0-10)	0	1.7 (0-3)	2.0 (0-10)
Mean garden size in m2 (range)	151.0 (0-900)	741.4 (30-3,200)	453.9 (16-3,200)	273.8 (0-3,200)
Average years lived in current home (range)	11.2 (0.1-50.0)	9.4 (0.2-55)	6.9 (0.1-39)	9.7 (0.1-55.0)
Drinking water source				
Tap in HH/garden	120	0	0	120
Tap on street	0	11	13	24
Tap at neighbors	0	9	14	23
Well	3	22	19	44
Vendor	1	9	5	15
River	0	11	7	18

* HH = household

To assess water consumption, sanitary conditions, socio-economic status, and health status, we developed a questionnaire that was translated into Russian and back-translated into English for content verification. The questionnaire was field-tested and revised by six interviewers who were native to Nukus and fluent in Russian as well as the regional language of Karakalpak.

Using computer-generated random integers, we divided the 120 households without piped water into two groups: an intervention and a nonimervention group. A 1.5% chlorine stock solution and a narrow-necked water container with a spout were provided to the intervention group. Members of the intervention households were taught to add chlorine solution to each newly collected container of water. Because water was dispensed through a tap on the container, neither hands nor utensils could be immersed in the chlorinated water. thereby preventing recontamination. Members of households in the intervention group also received hygiene education and were asked to obtain all of their drinking water only from the provided container and to wash their fruits and vegetables only with this chlorinated water.

Water samples collected from selected water sources and households underwent microbiologic analysis for fecal coliform. A sterile 250-ml polypropylene container was used for water collection. The water was stewed at 4°C and analyzed within 24 hr. Duplicate samples of 100 ml were filtered through a membrane and incubated at 45°C on liquid m-TEC medium (Difco Laboratories, Detroit, MI) for 18 hr[1]. The average of the duplicate colony counts was taken if the counts ranged between 0 and 200. A count exceeding 200 colonies per 100 ml was recorded as 200, and less than one as 0.

Interviewers visited 240 households in the study (120 without piped water and 120 with piped water) twice a week for 9.5 weeks. Study participants did not know the specific day or time at which the interviewers would return. In a brief interview using standardized questions, interviewers recorded occurrences of diarrhea and dysentery reported by an adult member of the household as well as the age and sex of the affected individuals. Diarrhea was defined as three or more liquid stools over a 24-hr period. People with diarrhea had to report having had no diarrhea at one of the twice-a-week visits before they could be counted as experiencing another episode. Self-reported dysentery was defined as a diarrheal episode with visible blood in the stool.

Interviewers regularly monitored compliance in the intervention group by testing the water in the containers for both free and combined chlorine levels with the N,N, diethyl-p-phenylene diamine sulfate (DPD) colorimetric method, and by checking the remaining volume of the concentrated chlorine solution. Questionnaire data were double-entered into Epi-lnfo (CDC, Atlanta, GA) for analysis. Diarrheal surveillance was documented and verified by comparing original questionnaires to an Excel (Microsoft. Redmond. WA) spreadsheet.

We calculated the diarrhea rate for each household, while controlling for intra-household correlation. The household rate was defined as the number of episodes of diarrhea in a household over the study time period divided by the number of people in that family. The mean household rate was compared with each cohort using a t-test with each household having equal weight. We used a Taylor series approximation to calculate confidence intervals (CIs). Relative risks (RRs) wore calculated by dividing the average diarrheal rates for we cohort by that for the referem cohort.

We used logistic regression for the univariate analysis of 50 potential risk factors for diarrhea for all ages per household. Because of possible intra-household correlation, we again used the household as the unit of analysis. The outcome of each household was defined as 0 for no diarrhea cases, and as 1 if there were one or more cases. All models controlled for the number of subjects in the household. Varibles that were significant in the crude, univariate analysis on the 0.1 level were entered into a stepwise logistic-regression model.[2] The final multivariate model contained the variables that were meaningful predictors (P = 0.1) of diarrhea.

RESULTS

A total of 818 females and 765 males living in the 240 homes were included in the study. Of these participants, 344 were children less than five years of age (Table 1) and of these 344 children, 115 (71 boys and 44 girls) were breast-fed during the study period.

Water. Boiling and settling the drinking wafer prior to consumption were the most common water treatments used in all three groups. Prior to the intervention, none of those interviewed reported filtering or chlorinating their water. The origin of source water for the different groups is listed in Table 1. Of those households with piped water on the premises, three also had a well and one also obtained water from vendors. All wells tested (n =7) were found to be contain inated with coliforms (mean as 54 colonies/100 mi). Comparison of coliform density of water samples taken from household water containers in the intervention group (n = 15) and the nonintervention (n = 11) group with no piped water showed that they were not statistically different (comparison of no intervention versus intervention by the Wilcoxon rank sum test: P = 0.97; mean = 52 versus 47 colonies/100 ml. median = 40 versus 47 colonies/100 ml. range = 0 to > 200 versus 2 to > 200 colonies/100 ml).

An investigation of chlorine levels in all of the 120 study households with piped water revealed that at the beginning of July 1996, water in 45 (38%) of the houses lacked any detectable levels of free or bound chlorine as measured by the DPD colorimetric method. The water in 32 (27%) of the houses lacked detectable levels when retested at the end of July 1996.

Sanitation and socioeconomic status. Interviewers reported visible feces inside the latrine or in the garbage can in 39 (17%) of the homes, and no toilet paper of other anal cleaning material in the latrine or toilets in 101 homes (43%). In subjective evaluations of the cleanliness of children, the household, and water containers, interviewers assessed that households in the areas with no access to piped water were in generally worse sanitary condition than those in the central city with piped water. This difference is also reflected in the contrast between socioeconomic status as classified by total family income or meat consumption (Table 1). However, interviewers found no dramatic difference in the number of years spent in the current home between residents with piped water and those without piped water: interviewees with access to piped water had resided in their current home for 11.2 years on average compared with 8.2 years among those without piped water (Table 1).

Diarrheal surveillance. Active diarrheal surveillance over 9.5 weeks revealed a mean monthly diarrheal rate of 75.5/1.000 among individuals with piped water on their premises and 179.2/1.000 among those without piped water on the premises (Figure 1). A similar comparison between the intervention group with home chlorination (rate = 28.9/ 1,000 individuals/month) and the group without home chlorination showed that home chlonnation reduced diarrhea by 85% (RR = 0.15, 95% CI = 0.07-0.31) (Table 2). Individuals living in households with access to piped water but without a detectable chlorine residual were at increased risk compared to households with detectable chlorine residuals (RR = 1.6. 95% CI = 0.7-3.7).

Diarrhea rates and relative risks for children less than five years of age are shown in Tables 3 and 4. Over the course of the study, three infants less than one year of age were reported by a family member to have died of diarrhea. One of the deceased was from a home with piped water, and two lived in houses in the nonintervention group in the area with no piped water. In each of the cases a household member reported that the deceased infant had bloody stools: however, independent confirmation from a health care provider could not be obtained.

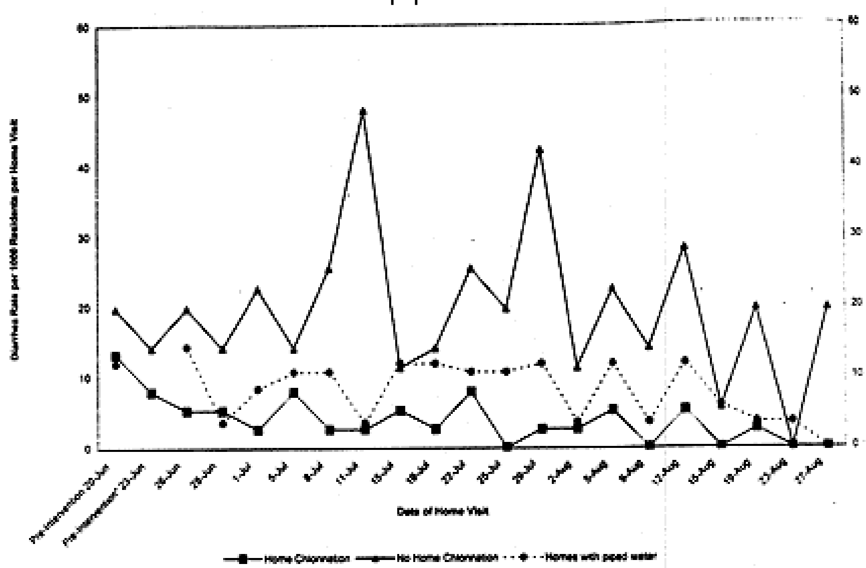
Despite the obvious advantages of clean drinking water, residents expressed little willingness to pay for 20 liters of clean drinking water (mean value per 20 liters = 7.2 Sum or $0.20) or a container for home chlorination (mean value per container = 12.6 Sum or $0.30). However, the home chlorination procedure was readily accepted by this population based on a compliance rate of 73% for detectable chlorine residuals in the water at the time of the visit.

In multivariate analyses with non-age-specific diarrhea within a household as the outcome and correcting for family size, water source and intervention status, we found the following variables (Table 5) to be risk factors: a water source farther than 200 meters from the residence compared with a source closer than 200 meters (OR = 2.2. 95% CI = 0.9-4.9). 20-40 liters of water stored in the house compared with less than 20 liters stored (OR = 2.2. 95% CI = 1.1-4.1), and more than 40 liters of water stored in the house (OR = 2.0, 95% CI. = 0.9-4.4). Use of toilet paper after defecating was found to be protective (OR = 0.7. 95% CI = 0.5-1.0).

DISCUSSION

Our active diarrheal surveillance, in combination with the randomized intervention study, revealed that poor water quality contributes to a substantial diarrheal burden for the population of Nukus that consumes municipal water. This conclusion is based on the following three findings. 1) Among people living in homes without piped water, those who were randomized to treat their water with chlorine had an 85% reduction in diarrheal rates, compared with those who did not chlorinate their water (Figure 1). This implies that a large fraction of diarrheal pathogens in Nukus are spread through water and that other routes of transmission play only a minor role. It is unlikely that chlorination of drinking water would affect disease transmission due to poor hygiene, lack of sanitation, inter-household or person-to-person transmission, or contaminated foods to the degree observed in the intervention group. 2) People in the home-chlorination intervention group had a 62% reduction in diarrheal rates compared with those living in areas with access to piped water, despite less sanitary conditions and lower income in the areas without access to piped water (Table 1 and Figure 1). This suggests that some, if not most, of the diarrhea among those with piped water is associated with the public water supply. 3) In approximately one-third of the households with piped water, the water did not contain adequate levels of chlorine, and 42% of the interviewees from households with piped water reported frequent loss of water pressure. As a result, leaky sewer lines or unsanitary ground water could cross-contaminate the drinking water pipes, which in turn would lead to both fecal spread and depletion of chlorine residuals. An indication of the hazard posed by the Nukus public water system is illustrated by the fact that people in houses without a chlorine residual in their piped water experienced 60% more cases of diarrhea than did those with a chlorine residual in their piped water. This finding is not statistically significant and should only be taken as supporting evidence.

FIGURE 1. Diarrhea rates in Nukus, Uzbekistan by chlorination status. June-August 1996. *No data for area with piped water.



These three sets of findings all indicate that contaminated drinking water is a major cause of diarrheal diseases in Nukus. Because the water supply is chlorinated twice at the plant, it is likely that the distribution system is a primary source of diarrheal pathogens. Increasing the amount of water available would help maintain pressure in the pipes and decrease cross-contamination. Availability can be increased by minimizing water loss through proper management of the distribution system. Under current conditions, water that passes through the two-step clilorination process is believed to become recontaminated in the distribution system, and the quality of the drinking water is therefore suboptimal. Likewise, highly purified water from a reverse osmosis plant can only reach consumers through an intact distribution system with no cross-contamination, a situation that our study indicates does not currently exist in Nukus. Based on the results of this study, Nukus health officials improved management of water distribution by locating and repairing leaky pipes. Furthermore, reverse osmosis was abandoned as a treatment option and water quantity will be increased in the near future.

TABLE 2: Comparison of diarrheal burden among three study groups over a 9.5-week period using the household (HH) as a unit of analysis*

Study group comparison	No. of HH	RR	95% CI
No home chlorination	58	1 (ref.)	-

Home chlorination	62	0.15	0.07-0.31
Piped water	120	0.45	0.34-0.59

RR =relative risk
95% CI = apporoximate 95% confidence interval
ref =reference

TABLE 3: Diarrheal rates among children less than five years of age by study group

Study Group	Total no. of Children	Children / household	Number of Households	Total episodes	Rate/1,000 children/month
Home chlonnation	88	1.42	62	14	42.2
No home chlonnation	80	1.38	58	80	127.7
Piped waier	176	1.47	120	72	84.4

TABLE 4: Comparison of diarrheal disease rates among children less than five years of age in the 3 study groups, from June 26 to August 17, 1990*

Study Group	Number of households	RR	95% CI
Home chlorination vs. no home chlorination (intervention vs. control)	62 vs. 58	0.33	0.19-0.57
Home chlorination vs. piped water	62 vs. 120	0.50	0.29-0.84
No home chlorinaiion vs. piped water	58 vs. 120	1.5	1.05-2.13

TABLE 5: Association of risk factors with diarrhea for all ages in household in multivariate analysis*

Design variables	Odds ratio (95% CI)
Home chlorination status	0.2 (0.1-0.4)

Piped water access	0.9 (0.4-2.0)
Family size	
Exposure variables	
Distance to water source =<200 meters (ref.)	1
Distance to water source >200 meters	2.2 (1.0-4.9)
Clean after defecating: other (ref.)	1
Clean after defecating: paper	0.7 (0.5-1.0)
Liters of water stored in home < 20 (ref.)	1
Liters of waier stored in home >20<=40	2.2 (1.1-4.1)
Liters of water stored in home >40	2.0 (0.9-4.4)

* CI =confidence interval; ref. = reference.

Prevention of diarrheal diseases is an important public health strategy for reducing morbidity and mortality, paricularly among children less than five years of age. In enteric disease outbreaks, sources of infection have been traced to a variety of origins such as surface water, household water containers, foods and drinks, and poor sanitary conditions. Contaminated municipal water supplies have been implicated in disease transmission in diarrheal outbreaks around the world.[6,8-13] However, few studies to date have evaluated the burden and routes of transmission of enteric diseases in relatively developed countries with suboptimal sanitary infrastructure, such as the newly independent Central Asian States. Our analysis of disease transmission in Nukus reveals that in this case the endemic disease burden is caused primarily by contaminated public water supply rather than by poor sanitation, poor hygiene practices, or other causes.

Besides remediating the municipal water supply it is also important to extend piped water services to houses in the periphery of Nukus, which disproportionately suffer from diarrheal diseases. Implementation of water treatment with delivery systems as well as sewage treatment plants are obviously desirable measures, but are often hampered by the fact that they are expensive, time-consuming, and laborious to construct. In fact, the lack of piped water in these outlying neighborhoods of Nukus is not a recent occurrence, as reflected by the number of years occupants lived in their homes, and indicates an ongoing developmental problem. A short-term alternative involves the use of a narrow-necked water container with spout and chemical disinfectant such as that used in this and other studies.[14-16] Our data suggest that this simple combination of water disinfection and a physical barrier to recontamination, if used appropriately and supplemented with hygiene education, can be an affordable, effective short-term means of reducing diarrheal rates in those areas where potable water is currently not available. Our study not only documents the feasibility and effectiveness of this method but also establishes the behavioral and cultural willingness of our study population to adopt such an intervention, provided the containers are made available. As part of a training course in environmental epidemiology, local health officials participated in this study; the goal was to illustrate a study design appropriate for local circumstances, relying on limited infrastructure and resources but nevertheless powerful in its conclusions.

Throughout the study, we monitored the durability of the narrow-necked, flexible, plastic water containers used by the intervetion group. Because of leaks and punctures, 19 of the 62 containers had to be replaced, indicating a half-life of 4.9 months for this type of container. This suggests the need for more durable water containers, and the effectiveness of locally produced aluminum containers will be assessed in nonintervention households in the coming months.

The intervention group, in addition to having access to disinfected water, may have changed their sanitary habits during the course of the study, and such behavior modification may have contributed to their reduced diarrheal rates. Besides being instructed to use chlorinated water for drinking purposes, intervention households were also asked to wash their fruits and vegetables with the treated water. This guidance, together with the fact that the intervention group received a valuable container, may have led to improved hygienic behavior among members of this group. However, we do not believe that this is the case for the following reasons: hygiene practices were observed to be at a consistently high level in all three study groups, especially with regard to hand washing and food washing; our hygienic message was brief and not reinforced: there is no reason to believe that prior differences in hygiene practices existed in the different groups; and during the intervention all three groups received equal numbers of visits and similar amounts of attention. The purpose of our message was to emphasize that this water was not only for drinking but also for food preparation. It is possible that members of me intervention group were more likely to wash their food because they knew their water was treated. In this case, an increased tendency to wash food should be viewed as an indirect benefit of chlorination that would likely occur elsewhere in this population when safe domestic water becomes available.

Overall, inhabitants of Nukus have a considerable burden of diarrheal diseases regardless of their water source, compared with locations where drinking water meets current microbiologic standards.[12] Individuals with access to piped water at their residence experience fewer episodes of diarrheal disease than those without access to piped water. Nonetheless, drinking home-chlorinated water results in lower diarrheal incidence than drinking the piped water provided in Nukus. This is probably due to cross-contamination between water lines and unsanitary ground water which results in a depletion of chlorine levels in the piped water. Thus, providing water with adequate chlorination levels to all residents should be the top priority of Nukus health officials. In fact, this study resulted in better system management with a focus on maintaining pressure throughout the distribution system, accompanied by monitoring to ensure that pressure remains stable. Until the distribution system can deliver uncontaminated water to households in Nukus, reverse osmosis treatment has no technical, financial or public health basis and has indeed been abandoned.

Acknowledgments: We are particularly grateful to Drs. G. Heitbaev and A. Mustanna of the Sanitary-Epidemiologic Services (SES), Nukus for support of the field investigation. We also thank Paul Dryer (EPT), Bruce Ross and Dr. Terence Chorba (CDC, Almaty, Kazakhkstan), and Maureen Blyler (CDC, Atlanta). Finally, many thanks are given to the people of Nukus, who were warm and open, and endured both the hardship of life and the taste of chlorine with a smile.

Financial support: This study was funded by the United States Agency for International Development (USAID). the Environmental Policy and Technology Project (EPT), and CDC. The work was facilitated by U'SAID/Central Asian Republics

and undertaken jointly by the SES of Uzbekistan, SES Karakalpakistian, EPT, and CDC.

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Suggested citation:

Semenza J, Roberts L, Henderson A, Bogan J, Rubin C. Water distribution system and diarrheal disease transmission: a case study in Uzbekistan. American Journal of Tropical Medicine and Hygiene 1998; 59: 941-6.