A Massive Epidemic of Multidrug-Resistant Typhoid Fever in Tajikistan Associated with Consumption of Municipal Water

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From 1 January through 30 June 1997, 8901 cases of typhoid fever and 95 associated deaths were reported in Dushanbe, Tajikistan. Of 29 *Salmonella* serotype Typhi isolates tested, 27 (93%) were resistant to ampicillin, chloramphenicol, nalidixic acid, streptomycin, sulfisoxazole, tetracycline, and trimethoprim-sulfamethoxazole. In a case-control study of 45 patients and 123 controls, *Salmonella* Typhi infection was associated with drinking unboiled water (matched odds ratio, 7; 95% confidence interval, 3–24; $P < .001$). Of tap water samples, 97% showed fecal coliform contamination (mean level, 175 cfu/100 mL). Samples taken from water treatment plants revealed that fecal coliform contamination occurred both before and after treatment. Lack of chlorination, equipment failure, and back-siphonage in the water distribution system led to contamination of drinking water. After chlorination and coagulation were begun at the treatment plants and a water conservation campaign was initiated to improve water pressure, the incidence of typhoid fever declined dramatically.

Tajikistan, one of five Central Asian countries formerly part of the Soviet Union (figure 1), has an estimated population of 6 million, of whom ~600,000 live in the capital, Dushanbe. Soon after declaring independence in 1991, the nation experienced civil war. Although a cease-fire was declared in 1996, sporadic fighting has occurred, the economy has suffered, and the country's infrastructure has continued to deteriorate.

In mid-1996, an epidemic of typhoid fever began in southern Tajikistan [1]. By February 1997, the epidemic had reached Dushanbe, where 2200 cases of typhoid fever were reported during a 2-week period. Central governmental edict required a minimum 25-day hospitalization of patients with typhoid fever; hospitals in Dushanbe were filled to capacity and most accepted only patients with typhoid fever. Initial laboratory reports indicated that the epidemic strain of *Salmonella* serotype Typhi (formerly *S. typhi*) was resistant to most commonly prescribed antibiotics for typhoid fever treatment. The Ministry of Health advised that all drinking water be boiled, and the city government prohibited street vending of food and beverages. However, there remained considerable debate about the cause of the epidemic and appropriate control measures.

Deaths occur in ~15% of untreated cases of typhoid fever [2, 3]; however, in areas where appropriate antimicrobial and supportive therapy is available, <1% of patients die [4–6]. *Salmonella* Typhi infects only humans and is spread most frequently through ingestion of contaminated food or water. Patients excrete *Salmonella* Typhi in their stool for several weeks following infection. About 5% of persons infected with *Salmonella* Typhi become asymptomatic chronic carriers and intermittently shed the bacteria in their stool for years.

The city of Dushanbe receives water from four treatment plants: two surface water treatment plants supplied by the Varzob River and two groundwater treatment plants supplied by deep wells. The water distribution system is interconnected, and different areas of the city are supplied with varying amounts of water from the four plants. Low and intermittent water pressure is common. During water outages, negative pressure is created in water pipes that draw surrounding contaminants into the water supply. Many apartment buildings have supplemental water pumps that are activated at times of low water pressure, causing negative pressure in nearby municipal pipes. In addition, nonstandard connections to major water lines are commonly used to supply homes, and water pipes are observed running inside storm drains alongside roads. These situations increase the possibility of back-siphonage and consequent cross-contamination of drinking water with sewage. Although

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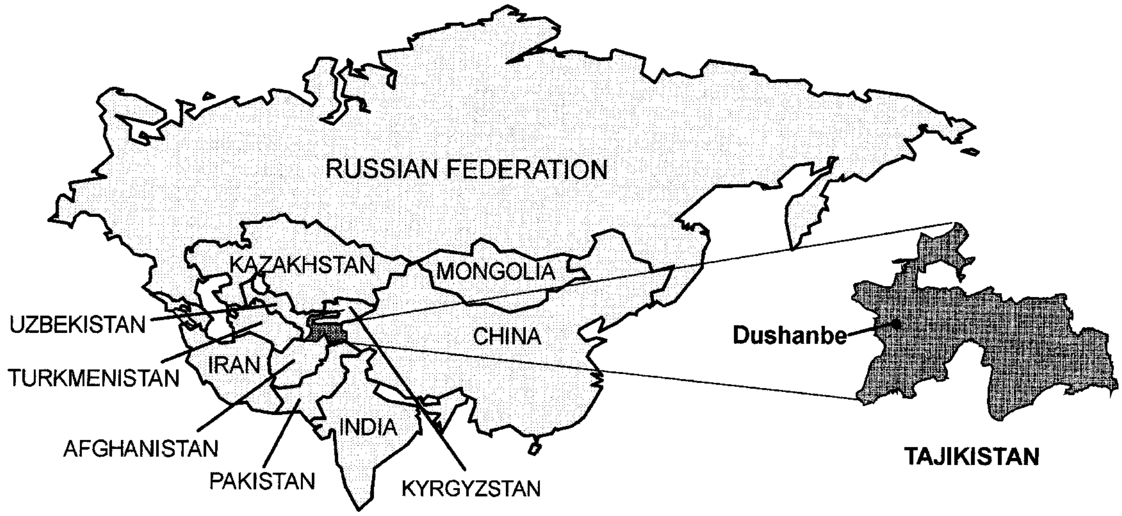

Figure 1. Map of Central Asia and Tajikistan

water is usually chlorinated at the treatment plants, due to lack of supplies, this was not done regularly after December 1996.

Materials and Methods

Typhoid fever surveillance. Dushanbe residents receive primary health care at 12 clinics serving separate geographic areas of the city. Information on the total population served by each clinic catchment area was obtained from the Dushanbe Sanitary and Epidemiologic Service (SES). Each clinic maintains a register for persons with clinically diagnosed or bacteriologically confirmed typhoid fever. The clinical definition used to define a case of typhoid fever is nonstandardized and relies on physician judgment. Bacteriologic confirmation required isolation of *Salmonella* Typhi from a blood or stool sample. Cases of typhoid fever and all deaths in a clinic area are reported to the clinic, which issues a certificate required for burial. The Dushanbe SES provided information on age, sex, date of symptom onset, city of usual residence, clinic visited, bacteriologic test results, and mortality for all reported patients with typhoid fever registered in Dushanbe from 1 January 1996 through 30 June 1997.

Case-control study. On 22 March 1997, detailed hypothesis-generating interviews to detect common exposures were conducted with 4 patients with blood culture–confirmed *Salmonella* Typhi infection. Exposures common to these patients or known to be risk factors from previous large outbreaks of typhoid fever were included in a questionnaire for a case-control study. From 24 March through 7 April 1997, patients were recruited to participate in the study from two hospitals in Dushanbe. A case was defined as symptoms and signs consistent with typhoid fever in a Dushanbe resident with *Salmonella* Typhi infection confirmed by blood or stool culture. If >1 patient from the same household had *Salmonella* Typhi infection, only illness in the patient with the earliest date of symptom onset was included as a case. Patients were interviewed within 5 days of hospital admission by a trained interviewer using a standard questionnaire. Questions focused on potential risk exposures during the 30 days before symptom onset. Exposures examined included drinking boiled and unboiled water; obtaining drinking water from a tap outside the home; drinking beverages with ice; eating or drinking food or beverages at restaurants or purchased from street vendors, or at the homes of friends or relatives; travel outside Dushanbe; having visitors who normally reside outside Dushanbe; consuming certain food items (e.g., raw fruits and vegetables and dairy products); and taking antacids or antimicrobial agents.

Within 5 days of interview, we selected 2 to 3 neighborhood- and age-matched controls from households in which no one had experienced fever for ≥ 3 consecutive days during the previous 90 days. Controls were matched by neighborhood and age to control for socioeconomic status and to increase power to elucidate individual risk behavior that might be associated with acquiring typhoid fever. We found control homes by going door-to-door systematically from the associated case home. Each case and control home was visited and information recorded about the presence of a toilet or latrine, the existence of soap in the kitchen or toilet area, and type of water storage vessels. Controls were interviewed using a standardized questionnaire identical to the case questionnaire, except that potential risk exposure information was requested for the 30 days before the interview.

Laboratory investigation. Blood and stool samples from patients with suspected typhoid fever at two Dushanbe hospitals were examined for *Salmonella* Typhi by standard methods [7]. Patients with *Salmonella* isolates confirmed as *Salmonella* Typhi were enrolled in the case-control study. Antimicrobial susceptibility testing using the disk diffusion method [8] was performed on 29 *Salmonella* Typhi isolates obtained during routine surveillance from patients at hospitals throughout Dushanbe. Twelve antimicrobial agents were evaluated: amoxicillin/clavulanic acid, ampicillin, ceftriaxone, chloramphenicol, ciprofloxacin, streptomycin, sulfisoxazole, tetracycline, trimethoprim/sulfamethoxazole, gentamicin, kanamycin, and nalidixic acid. MICs of nalidixic acid and ciprofloxacin were determined for 4 isolates by Etest (AB Biodisk, Piscataway, NJ).

Water sampling and wastage study. We selected households for water quality and wastage testing using stratified random sampling by individual clinic area. Two sampling points within each clinic catchment area were determined by choosing a random latitude and longitude within the area. By use of a geographic positioning system, we went to each point and marked 100-meter squares with the initial points as the southeastern corners. Dwellings nearest the starting point, the northwest corner, and the midpoint of each hectare were visited. If dwellings were multistory, a floor was chosen at random. We recorded the number of residents in each house or apartment, collected a water sample from the tap, and quantified water wastage. Wastage was considered to be drips, broken or running taps and toilets, or taps left on at the time of arrival and not being actively used. All open taps were closed, and any remaining flows were measured again. Wastage was considered voluntary if closing the tap decreased water flow and involuntary if the tap or pipe was broken. All areas not in a private dwelling were inspected for water wastage. Public water wastage was measured by surveying the sample hectare and recording flows from all outdoor broken pipes and open taps. The number of houses and apartments in each hectare was recorded. Industrial, commercial, or vacant areas were evaluated for water loss, and the population was recorded as zero.

Water quality testing. A portable water testing kit (Oxfam-DelAgua, Guildford, UK) was used for microbiologic analysis. Water was collected in sterile polypropylene bottles, and 50-mL samples were filtered through 0.45-μm, 47-mm diameter, cellulose nitrate filters. Each filter was transferred to 60-mm petri plates containing laurel tryptose broth medium on Gelman absorbent pads. The samples were incubated at 44.5°C for 18 h. Fecal coliform bacterial densities/100 mL were calculated from colony counts. If the filters had colonies too numerous to count, a conservative estimate of 400 cfu/100 mL was used in calculation of means. Water hardness was measured by test kit (model 5-EP; Hach, Loveland, CO). Turbidity was measured by Jackson turbidimeter (Oxfam-DelAgua). Free and total chlorine residual were measured by Hach model CN-66 test kit.

Assessment of water treatment plants. At the surface water treatment plants, turbidity was measured following each stage of the treatment process, and samples were obtained for microbiologic analysis at the inflow and outflow of the facilities. Only finished water samples were taken from the two groundwater facilities.

Statistical analysis. We analyzed surveillance and case-control data using Epi-Info software (version 6.03; Epidemiology Program Office, CDC, Atlanta). Univariate matched odds ratios (MORs) were calculated for exposures and illness by Mantel-Haenszel summary χ^2. All P values were 2-tailed; $P < .05$ was considered significant. Multivariable conditional logistic regression analysis was done with SAS software (SAS, Cary, NC).

Results

Typhoid fever surveillance. From 1 January 1996 through 30 June 1997, 10,677 cases of typhoid fever and 108 deaths (1.0%) were reported in Dushanbe; 8901 (83%) of these cases and 95 deaths (88%) occurred during the first half of 1997 (figure 2). The median age of patients was 16 years (range, <1–80); 51% were male. The median time from onset of symptoms to hospitalization was 6 days. The mortality rate was lowest among patients <10 years old (8 [0.3%] of 2303) and highest among those >39 years old (9 [1.4%] of 631). No major differences in demographic variables or mortality were observed between cases with symptom onset in 1996 and those with onset in 1997. Blood or stool cultures confirmed 3294 (31%) cases.

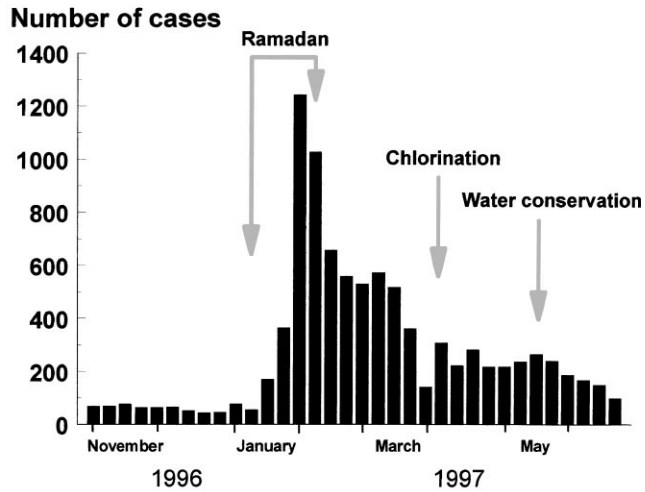

Figure 2. Typhoid fever cases by week of onset, Dushanbe, Tajikistan, 29 October 1996–24 June 1997. Arrows indicate dates when Ramadan began (10 January 1997) and ended (8 February 1997), when chlorination of municipal water system resumed (5 April 1997), and when water conservation campaign was initiated (15 May 1997).

The mean number of cases per week varied considerably. During 1–21 January 1997, an average of 100 cases occurred per week (figure 2). Because the median incubation period for typhoid fever is ~10 days, this period represented exposures during the 3 weeks before the onset of Ramadan, a month-long Muslim observance involving a fast from food and water from sunrise to sunset that began on 10 January 1997. From 22 January through 18 February (the period representing infections acquired during Ramadan), the mean number of cases was 823 per week. From 10 February through 8 April (the period following Ramadan and before chlorination of the water supply began), the mean number of cases was 427 per week. From 9 April through 27 May 1997 (when the municipal water utility began chlorination), the mean number of cases was 241 per week, and from 28 May through 24 June 1997 (a period when the water was chlorinated and after a water conservation campaign was begun), there was a mean of 150 cases per week.

Case-control study. A total of 45 patients and 123 healthy controls were enrolled in a case-control study. Median age of patients was 13 years (range, 3–41); 62% were male. By univariate analysis, illness with bacteriologically confirmed *Salmonella* Typhi infection was associated with drinking unboiled water during the 30 days before symptom onset (MOR, 6.5; $P < .001$) and obtaining water for the home from a tap outside the house (MOR, 9.1; $P = .003$; table 1). Eating food obtained from street vendors also was associated with illness (MOR, 2.9; $P = .004$. Several practices or exposures were protective against typhoid fever: boiling water in the home before drinking it and eating butter, apples, or onions.

By multivariable conditional logistic regression analysis, illness remained associated with drinking unboiled water (MOR, 9.6; confidence interval [CI], 3–34; $P < .001$) and obtaining water from an outside tap (MOR, 16.7; CI, 2–138; $P = .009$). To further examine drinking unboiled water as a risk factor for typhoid fever, we calculated MORs at separate levels of exposure measured by number of glasses consumed per day. The odds of having typhoid fever increased dramatically with the amount of unboiled water drunk per day: drinking 1 glass of water had an MOR of 3 (CI, 2–7), drinking 2 glasses had an MOR of 12 (CI, 6–22), and drinking >2 glasses had an MOR of 40 (CI, 21–75).

Boiling water in the home was inversely correlated with drinking unboiled water—precluding the analysis of both variables in the same multivariable regression model. In a separate model that did not contain drinking unboiled water but contained other associated exposures, boiling water in the home was independently protective, with an MOR of 0.2 (CI, 0.05–0.6; $P = .006$). In both models, eating 2 food items, butter and apples, remained protective against typhoid fever.

Laboratory investigation. Of 29 *Salmonella* Typhi isolates, 27 (93%) were resistant to ampicillin, chloramphenicol, nalidixic acid, streptomycin, sulfisoxazole, tetracycline, and trimethoprim-sulfamethoxazole and susceptible to amoxicillin/clavulanic acid, ceftriaxone, ciprofloxacin, gentamicin, and kanamycin. One isolate (3%) was resistant to sulfisoxazole and streptomycin only, and 1 isolate (3%) was sensitive to all agents. For 3 isolates resistant to nalidixic acid but sensitive to ciprofloxacin by disk diffusion, nalidixic acid MICs were >256 μg/mL and ciprofloxacin MICs were 0.25 μg/mL. For 1 isolate sensitive to ciprofloxacin and nalidixic acid on disk diffusion, the MICs were 8.0 μg/mL and 0.03 μg/mL, respectively.

Water treatment plant evaluations. Both surface water treatment plants used sedimentation and filtration to treat river water. Algae were growing in the silt-filled sedimentation basins. At one plant, the turbidity of the water taken before treatment was 7 turbidity units (JTU); after treatment it was 15 JTU (indicating a decrease in water clarity after treatment); fecal coliforms decreased from 440 to 132 cfu/100 mL. At the other plant, the turbidity of the source water was 27 JTU, which decreased after treatment to 7 JTU; fecal coliforms decreased from 460 to 118 cfu/100 mL. Both groundwater plants pumped fecal coliform–free water from the aquifer. About half of the pumps at all four plants were not operational, limiting the ability to provide the city with adequate water pressure.

Water from different treatment plants was mixed within the distribution system of the city. In addition, the western portion of the city received unfiltered surface water through a siphon from the main sedimentation basin at one of the treatment plants, and the catchment area for clinic 11 received a mixture of spring water and unfiltered, unchlorinated river water.

The chlorine-producing facility in Yavan, Tajikistan, which once supplied chlorine to Tajikistan and several other Central Asian countries, was closed in 1996; a site visit revealed no salvageable equipment. From December 1996 to the beginning of April 1997, no chlorine was available at any of the treatment plants.

Water quality testing. Of water samples from homes or community taps throughout the city, 97% contained fecal coliform bacteria, indicating contamination by animal or human feces. The average concentration of fecal coliforms in finished water leaving the surface water treatment plants was 163 cfu/100 mL and for water at the wellheads at the two groundwater plants, 0 cfu/100 mL. Flow-adjusted average concentration of fecal coliforms for water leaving the four treatment plants was 60 cfu/100 mL. The average fecal coliform concentration in water samples taken from household and community taps throughout the city was 175 cfu/100 mL (range, 0 to >400), triple the calculated concentration in water leaving the plants. This indicates that water contamination increased during passage through the distribution system after water left the treatment plants.

Water hardness testing. Surface water and groundwater were blended in the water distribution network. To distinguish the source of water supplied to different areas of city, we measured the hardness of water samples collected at the treatment plants and in different sampling areas. Level of water hardness reflects the concentration of dissolved minerals and is higher for groundwater than for surface water. The average hardness

Table 1. Association of reported exposures with *Salmonella* Typhi infection, Dushanbe, Tajikistan, 1997.

Exposure	Patients exposed/ no. reported (%)	Controls exposed/ no. reported (%)	Matched odds ratio	95% confidence interval	*P*
Unboiled water[a]	19/39 (49)	12/117 (10)	6.5	3.–24	<.001
Water for home obtained from outside tap[a]	10/42 (24)	10/116 (9)	9.1	1.6–82	.006
Eating food obtained from street vendor	23/42 (55)	35/117 (30)	2.9	1.4–7.2	.004
Boiled water in home[a]	30/42 (71)	108/113 (96)	.2	.05–.5	<.001
Apples[a]	34/43 (79)	109/117 (93)	.3	.08–.9	.03
Butter[a]	8/43 (19)	60/116 (52)	.2	.06–.5	<.001
Onions	21/43 (49)	81/117 (69)	.5	.2–1.0	.04

[a] Significantly associated with illness on multivariable logistic regression analysis.

of water at the groundwater plants was 300 mg/L as $CaCO_3$, and at the surface water treatment plants, 100 mg/L as $CaCO_3$. The hardness measurements throughout the city reflected the degree of blending between the surface water and groundwater; the northern sections of the city were served primarily by surface water (<100 mg/L as $CaCO_3$), the southern sections by groundwater (>200 mg/L as $CaCO_3$), and the middle sections by a mixture of surface and groundwater (100–200 mg/L as $CaCO_3$) (figure 3). The one exception was the area for clinic 11 at the northernmost part of the city, which was supplied by a mixture of untreated river water and water from a small well, and thus had an intermediate level of hardness.

To determine whether the incidence of typhoid fever was correlated with drinking water source, we calculated the incidence of typhoid fever per clinic catchment area. From 1 January 1996 through 30 June 1997, the rates of typhoid fever per catchment area ranged from 0.6 per 100 residents to 3.3 per 100 residents. The incidence of typhoid fever did not follow the proportional distribution of surface or groundwater throughout the city (figure 3), suggesting that the source of water was not related to risk of infection.

Water outages and wastage. Water outages were common in Dushanbe; 50% of households in the case-control study reported routine daily outages lasting a median of 6 h. The inability of the municipal water system to keep up with demand was exacerbated by excessive water wastage. The water use survey found that, on average, 1000 L of water was wasted per person per day. Average household water wastage was 600 L per person per day, 300 L of which could be prevented simply by closing taps and 300 L of which was due to broken pipes or faucets. An additional 400 L per person per day of water waste resulted from open or broken taps or pipes in public areas.

Interventions. Several measures were taken by central and local government and international agencies to control the epidemic. These included assisting with repairs and obtaining chlorine and coagulants for the water treatment plants; initiating health education and water conservation campaigns using posters, television, and targeted programs for schoolchildren; providing ciprofloxacin to hospitals; and continuing active surveillance of the epidemic.

Discussion

During the first 6 months of 1997, typhoid fever was reported in 8901 persons in Dushanbe, ~1% of the city's population. Two exposures were associated with increased risk for typhoid fever: drinking unboiled water and obtaining water from outside the house. Drinking unboiled water was associated with the largest proportion of cases (49%), and there was a dose-response effect as the number of glasses drunk per day increased. Persons who usually drank boiled water in their home were protected from infection. Contaminated, inadequately

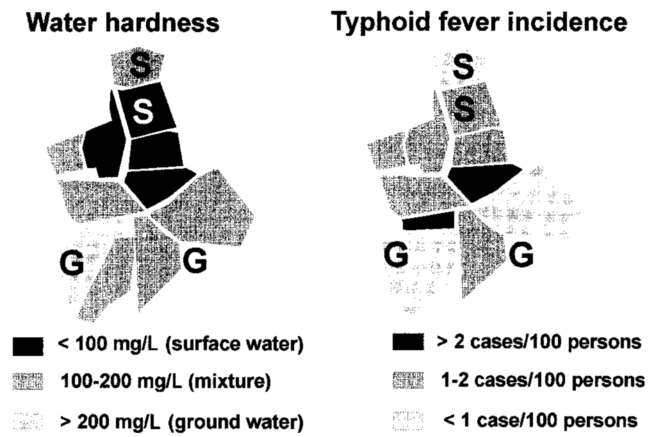

Figure 3. Maps of Dushanbe show water hardness (left) and typhoid fever incidence (right) by clinic catchment areas. Water hardness increases from northern to southern parts of the city, except for northernmost part, which was supplied by mixture of untreated river water and 1 small well and had intermediate hardness. Highest rates of typhoid fever did not correspond with areas receiving highest concentrations of surface water. S = surface water treatment plant, G = groundwater treatment plant.

treated river water was supplied to the municipal water system, and cross-connections, low water pressure, frequent water outages, and a lack of residual chlorine in pipes contributed to widespread increases in contamination within the distribution system. Obtaining water from a tap outside the house may have been a risk factor for illness because outside taps were more likely to be made with faulty plumbing, lie closer to latrines, or have attached hoses that allowed back-siphonage during water outages. Drinking water may also have been contaminated during storage in the home. Contamination of household drinking water during storage in open vessels has been implicated in outbreaks of *Vibrio cholerae* [9] and *Shigella* [10]. We did not find an association in this case-control study, although this may be due to the relatively high infectious dose of *Salmonella* Typhi [11] or to difficulty detecting the relatively small attributable fraction of cases caused by this mechanism during an epidemic primarily spread by contaminated municipal water.

Although selecting neighborhood-matched controls in the case-control study prevented us from directly implicating regional factors, such as water source, that might be associated with typhoid fever, the evidence from fecal coliform and hardness testing of water samples supports both contaminated river water and cross-contamination in the distribution system as sources of fecal contamination. The latter may be a more important source for illness because areas of the city with the highest incidence of typhoid fever were not the areas receiving the greatest proportion of surface water. One of the two clinic areas in the center of Dushanbe with the highest rate of typhoid fever received predominantly groundwater. It may be that to reach the center of the city, water from the treatment plants traversed a longer series of pipes and had lower pressure, thereby increasing the chance of contamination.

The large amount of water wasted increased the frequency of water outages and associated cross-contamination. Average total water usage in the United States and Europe is <500 L per person per day, while average wastage in Dushanbe was ~1000 L per person per day. This wastage was due in part to an aged water system in need of repairs and to residents' failure to turn off taps when they were not in use. Water has long been provided without charge in Dushanbe, and residents did not consider running water taps as wasteful or as a contributing factor to the typhoid epidemic.

Why did the incidence of typhoid fever increase dramatically at the end of January and beginning of February 1997? Failure to chlorinate the water supply and provide adequate amounts of water during times of peak use may have led to the high background rate of typhoid fever during late 1996 and early 1997 in Dushanbe, an area endemic for typhoid fever. After sundown on 10 January 1997, when Ramadan began, practicing Muslims may have increased their evening use of water for bathing and drinking, acutely stressing the system and potentially increasing back-siphonage throughout the city. This continued on a daily basis during the 4 weeks of Ramadan and may have resulted in the sharp increase in the incidence of typhoid fever from 100 cases per week for the exposure period just before the onset of Ramadan to 823 cases per week for the exposure period during Ramadan. After Ramadan, the rate was halved but was still higher than before the holiday, possibly because more city residents had been infected and were excreting *Salmonella* Typhi into the environment. The rate continued to decline after chlorination at the surface water treatment plants resumed and a water conservation campaign was initiated. Some cases of typhoid fever continued to occur, possibly because water outages still occurred and adequate chlorine levels were not detectable at all points throughout the distribution system or perhaps through transmission via other vehicles, such as foods contaminated by recently infected residents who continued to excrete *Salmonella* Typhi in their stool.

Multivariable regression analysis of our data indicated that consuming food or beverages obtained from street vendors was not associated with acquiring typhoid fever. This exposure has previously been associated with typhoid fever in Asia [12] and South America [13]. In Dushanbe, the effect of having a contaminated municipal water supply may have left street vending as a minor factor in the epidemic. As the quality of municipal drinking water improves, cases of typhoid fever from contaminated food, inside or outside the home, may become a more important factor.

We cannot think of a plausible biologic reason for butter and apples being protective against typhoid fever. Because most produce and dairy products asked about in this study generally had a protective effect, they may represent other factors not directly measured, such as socioeconomic status.

Of tested *Salmonella* Typhi isolates from Dushanbe, 93% were resistant to commonly used antimicrobial agents for typhoid fever. At the time of the epidemic, chloramphenicol was the drug most commonly used for initial therapy for typhoid fever in Dushanbe. Because of the high rate of resistance to chloramphenicol, alternative antimicrobial agents were recommended. Despite the observed in vitro resistance of these *Salmonella* Typhi isolates to antimicrobial agents, the case mortality rate of 1.0% was low. This may have been because patients sought medical treatment early, and, although most patients were initially given antimicrobial agents that were ineffective in the laboratory against the predominant strain of *Salmonella* Typhi, those who did not improve were promptly given antimicrobial agents to which circulating *Salmonella* Typhi strains were susceptible (e.g., ciprofloxacin or gentamicin). This selective use of effective agents and high-quality supportive care may have contributed to the low mortality rate.

Ciprofloxacin is an orally administered effective agent for typhoid fever. No ciprofloxacin resistance was detected in the patient isolates; however, resistance has been reported in *Salmonella* Typhi isolates from patients in Tajikistan [1]. MICs of nalidixic acid and ciprofloxacin (both quinolones) were similar in our study and the previous report; however, to indicate resistance to ciprofloxacin, we used an MIC break point of $\geqslant$4.0 μg/mL per National Committee for Clinical Laboratory Standards guidelines [8], and previous researchers used a break point of 0.5 μg/mL. A threshold value for ciprofloxacin resistance has not been clinically well established [14]. The clinical effectiveness of ciprofloxacin against this strain is supported by the relatively low mortality rate among patients. However, we were unable to conduct clinical studies during the epidemic, and any resistance of *Salmonella* Typhi to ciprofloxacin is a disturbing trend.

In addition to municipal water treatment, reducing water wastage will be critical to improving water quality, maximizing treatment plant efficiency, and decreasing typhoid fever transmission in Dushanbe. By increasing water pressure, episodes of back-flow and cross-contamination are reduced, and adequate chlorine levels are more easily maintained throughout the distribution system. Until the municipal water supply is safe throughout the city, people living in Dushanbe should boil their drinking water. Half the patients enrolled in the case-control study reported having chlorine bleach in their home, but none used it to purify drinking water. Home treatment of water with appropriate concentrations of hypochlorite solution (bleach) is a safe and effective alternative to boiling [15].

Another possible intervention was vaccination. Several safe and effective vaccines against typhoid fever have been developed, with immunity lasting 2–5 years [16]. However, surveillance for other enteric diseases was not being conducted in Dushanbe, and typhoid fever likely represented only one of many illnesses that were being spread through fecally contaminated water. An education campaign and improving water treatment have the important long-term potential benefits of not only reducing the incidence of typhoid fever but also preventing other waterborne infections.

Multidrug-resistant *Salmonella* Typhi has been associated with higher morbidity and mortality than drug-sensitive strains [17, 18]. Multidrug-resistant strains have been reported from the Indian subcontinent, Asia, Africa, Latin America, and among travelers to and from those regions [6, 19–22]. The potential for spread into other central Asian republics is of serious concern, because the economic and structural conditions of many cities in the region may be conducive to similar waterborne epidemics [23]. Improving surveillance for illnesses that are frequently waterborne, such as typhoid fever, cholera, and childhood diarrhea, and assessing water treatment and distribution systems could help target public policy and prevent considerable morbidity and mortality in the regions.

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