January 2000

Limited effectiveness of home drinking water purification efforts in Karachi, Pakistan

S P. Luby
Aga Khan University

A H. Syed
Aga Khan University

N Atiullah
Aga Khan University

M K. Faizan
Aga Khan University

S Fisher-Hoch
Aga Khan University

Original Report

Limited Effectiveness of Home Drinking Water Purification Efforts in Karachi, Pakistan

Stephen P. Luby, MD;* Amber H. Syed, MBBS;† Naureen Atiullah, MBBS;† Mohammad K. Faizan, MBBS;† and Susan Fisher-Hoch, MD‡

ABSTRACT

Objective: In many developing-country urban areas, municipally supplied water is not microbiologically safe. This study evaluated drinking water quality and effect of home water purification efforts in Karachi, Pakistan.

Methods: Members of 300 households, including 100 households who used the Aga Khan University Hospital Laboratory and 200 of their neighbors were interviewed. In 293 consenting households, structured observations were performed and drinking water was analyzed for the presence of coliforms, using the multiple tube fermentation technique.

Results: Although 193 of the 293 households (66%) reported using some method to purify their drinking water, including 169 (58%) who boiled their water, only 48 (16%) of the drinking water samples were free of coliforms. Although a combination of boiling and filtering was the most effective method of purification, only 38% of samples that had been boiled and filtered were free of coliforms.

Conclusions: Further refinements and evaluations of home-based efforts to purify and store water are needed.

Key Words: *developing country, drinking water, filter, Pakistan*

Int J Infect Dis 1999; 4:3–7.

An estimated 1.3 billion persons living in developing countries do not have access to safe drinking water.[1] Fecally contaminated drinking water is a major route of transmission for bacterial, viral, and parasitic human pathogens. Where available source water is not microbiologically safe, many different home-based approaches to securing clean water have been attempted, including boiling, filtration, chemical treatment, and solar disinfection, though the ongoing effectiveness of these approaches in the community, outside of intervention studies, is unknown.[2-5]

Karachi, Pakistan, is a developing-country mega-city with an estimated population of 9.9 million and a growth rate of 4.3% per year. Forty percent of Karachi residents live in squatter settlements where the leading cause of childhood death is diarrhea.[6] The urban infrastructure in Karachi, like other mega-cities in low income countries,[7] is inadequate. The expansion of the water supply distribution system is not keeping pace with the population growth, and services are compromised by frequent breakdowns. Thus, if people want clean water in Karachi, they must make efforts to purify it in their own homes. This study was conducted to evaluate the quality of drinking water in Karachi and the effect of the various home purification methods actually practiced by Karachi residents.

MATERIALS AND METHODS

Study Population

The data for this analysis comes from a larger study of risk factors for infection with *Salmonella typhi* conducted in Karachi.[8] The original study enrolled 100 persons whose blood culture at the Aga Khan University Hospital Laboratory grew *S. typhi* between July and October 1994, and 200 age- and neighborhood-matched controls. The study found no difference in the water quality between case and control households; so for this analysis, water quality data from case and control households were combined and analyzed together. The Aga Khan University Hospital Laboratory in Karachi is a private university-affiliated laboratory that has clinical specimen collection points located throughout the city. Seventy-five percent of the laboratory's clinical specimens originate from physicians and patients who are not otherwise affiliated with the Aga Khan University Hospital, and include a substantial number of specimens from low-income persons who use the laboratory in times of serious illness.

*Assistant Professor and †Research Officer, Department of Community Health Sciences, and ‡Professor, Department of Pathology, Aga Khan University, Karachi, Pakistan.

Supported by an Aga Khan University seed money grant.

Received: May 3, 1999; Accepted: July 20, 1999.

Address correspondence to Dr. Stephen Luby, Centers for Disease Control & Prevention, Foodborne & Diarrheal Diseases Branch, Mail Stop A-38, 1600 Clifton Road, Atlanta, GA 30333. E-mail: sxl2@cdc.gov.

Home Visits

Trained interviewers administered a questionnaire to the study subjects (or to the primary care giver if the study subject was <12 y of age). The questionnaire included detailed questions on drinking water source or sources, methods used for purification, storage, and dispensing of drinking water, and socioeconomic indicators. An observational component was added a third of the way through the study to validate reported information about water purification and storage and to assess the cleanliness of the kitchen. The trained field investigators, using a structured observation form, went into the household kitchen, observed the boiling pots and storage vessels used for drinking water, and assessed the general cleanliness of the kitchen.

The field team collected drinking water samples from each of the consenting households. Field workers asked the respondents to identify the source where a household member would normally get a drink of water. Team members then collected 140 cc of drinking water from that source into sterile sampling bottles containing sodium thiosulphate to neutralize potential effects of chlorine. Samples were placed in a cooler on wet ice, and brought to the Aga Khan University Hospital Laboratory and tested for contamination with coliforms within 6 hours of collection, using the presumptive coliform test.[9] Initially, water samples were mixed directly with MacConkey broth at a 1:1 ratio in the presumptive coliform test. However, owing to the high frequency of contamination, two additional dilutions, at 1:10 and 1:100, were added. Ultimately, data were obtained on three dilutions in 235 water samples. Using these three dilutions and a standard nomogram, the most probable number (MPN),[10] a statistical estimate, of coliforms per 100 mL of water was derived.

Definitions Used in Analysis

The World Health Organization, maintains that coliform bacteria should not be present in drinking water and that its presence suggests inadequate treatment, post-treatment contamination, or excessive nutrients.[11] The authors classified the Karachi water samples as clean if they had an MPN of 0. Samples from early in the study, before three dilutions were tested, were classified as clean if water incubated at the highest concentration showed no growth.

During pre-testing, reported income did not appear to be consistent with subject's home and furnishings, so two other objective measures of wealth were used. The number of persons living the in the household was divided by the number of bedrooms and the number of toilets. A person-to-bedroom ratio over 3.0 indicated crowding, and person-to-toilet ratio over 4.0 was defined as toilet crowding.

Statistical Analysis

The quality of water between groups was compared by setting the group that used no purification method as a baseline and comparing other groups by relative risks. Greenland, Robins' approximation was used to estimate confidence intervals, and chi-square test, or Fisher's exact test where appropriate, was used to test statistical significance. Data were entered and analyzed using Epi Info.[12]

RESULTS

A questionnaire was administered to 300 households, and water samples from 293 were collected and analyzed. The MPN of coliforms was calculated for 233 (80%) households from which three dilutions were obtained. When the observational component was added later in the study, 221 households were approached for access into their kitchens; of these, 213 (96%) allowed the field team to enter and observe their kitchens.

Study subjects lived throughout Karachi. Their reported median monthly household income ranged between 5,000 and 10,000 Pakistani rupees (US$156–$312). Households used water from multiple sources (Table 1). Municipally supplied water was used by 261 (89%) of the 293 households, though 97 (37%) of these also received water from other sources.

Of the 293 households from which water samples were obtained, 193 (66%) reported using some method to attempt to purify their drinking water (see Table 1). Boiling was the most frequently reported method, being used by 169 (58%) of 293 households. Filtering, used by 33 households (11%) was the next most popular method. Sixteen (49%) of households who filtered their water also

Table 1. Sources of Water, Methods of Home Purification, and Storage Used by Karachi Residents, 1994

Variable	*Number of Households** *n = 293 (%)*	
Water source		
Municipal supply	261	(89)
Water tanker	57	(19)
Well	55	(19)
Mineral water	12	(4)
Community tap	9	(3)
Water salesman	4	(1)
Other	5	(2)
Method of purification		
Boiling	169	(58)
None	100	(34)
Filter	33	(11)
Alum	11	(4)
Purification tablets	5	(2)
Other	8	(3)
Storage vessel		
Insulated plastic vessel	170	(58)
Earthen pot	82	(28)
Metal tank	49	(17)
Other	13	(4)

*Some households had more than one drinking water source, some were practicing more than one method of purification, and some were storing water in multiple types of storage vessels.

Table 2. The Effectiveness of Various Methods of Purification Practiced by Citizens of Karachi, Compared to Drinking Water Samples Taken from Households That Made No Attempt to Purify Their Water

Purification Method	*n = 293*	*Clean* n (%)*	*Relative Risk*	*95% CI*	*P-Value*
None	100	9 (9)	1.0†		
Boiling	169	33 (20)	2.2	1.1–4.3	0.02
Boiling only	137	24 (18)	2.0	1.0–4.0	0.06
Boiling + other	32	9 (28)	3.1	1.4–7.2	0.01
Filter	33	8 (24)	2.7	1.1–6.4	0.03
Filter only	17	2 (12)	1.3	0.3–5.5	0.72
Boiling + filter	16	6 (38)	4.2	1.7–10.1	0.006
Mineral Water	12	5 (42)	5.0	2.0–12.8	0.0008

*Total coliform count = 0; †reference category for all comparisons in the table.

boiled it. The most common method of storing drinking water was in a plastic insulated water vessel (58%).

Of the 193 households that attempted to purify their water, 137 (71%) used boiling as their sole method for drinking water purification. Of the 169 persons who reported boiling their water, permission was requested to observe the kitchen of 132, of whom 128 (97%) agreed. The cooking pot used for boiling was identified in 122 (95%) of these kitchens. In 86 (67%) of these households, the boiling pot was full of water and in 120 (94%) the storage container for the drinking water was the same as that reported during the preceding interview.

Of the 293 drinking water samples tested, only 48 (16%) were clean. Of the 233 samples that were analyzed by all three dilutions, the median level of contamination with coliform bacteria was 350 colony forming units (CFU) per 100 mL.

Although water that was boiled and/or filtered was more likely to be clean than was unpurified water, a minority of the drinking water samples were clean no matter what method of purification was used (Table 2). Indeed, only 20% of boiled drinking water was clean. Although a combination of boiling and filtering was the most effective method of purification, only 38% of these samples were clean. Samples of commercially purchased mineral water, many taken from bottles previously opened, were more likely to be clean than water that was purified at home. However, 58% of the samples of mineral water were contaminated with coliforms.

Table 3. Relation between Length and Frequency of Boiling and Median of Most Probable Number of Coliforms per 100 mL of Water, Karachi 1994

	n (%)	*Median MPN Coliforms/100 mL Water*
Boiling time (min)		
1–3	28 (20)	173
4–5	24 (17)	110
6–10	42 (30)	388
>10	44 (31)	450
Unknown	2 (1)	4.5
Boiling per day		
Once	69 (49)	170
Twice	53 (38)	350
Three or more	15 (11)	80
Other	3 (2)	1800

MPN = most probable number.

There was no consistent relation between the reported length of boiling time or the number of times water was boiled per day and concentration of coliform bacteria (Table 3). Similarly, neither water storage nor indicators of income, including reported income range, less household crowding, and having fewer persons per toilet, were significantly associated with clean water (Table 4). However, households where kitchens were judged to be "very clean" or "clean" by the interviewers were 4.2 times more likely to have clean water compared to kitchens that were judged to be "dirty" or "very dirty" (23% vs. 5%, relative risk = 4.2, 95% CI = 1.6–11.5) (see Table 4).

DISCUSSION

Municipal water in Karachi is typically supplied to households for only a few hours each week through a distribution system notable for cross-contamination with ground water and the sewage system.[13] Despite widespread attempts to purify water in the home, only 16% of Karachi households in this study had clean water. This is markedly lower than the United Nation's estimate that 96% of persons living in urban Pakistan have access to safe water.[1]

The limited effectiveness of aggressive, theoretically sound household efforts to purify drinking water suggests important differences in laboratory versus developing-country home environments. The most likely explanation for these high levels of coliform contamination, despite 58% of the studied households boiling their water, is that water that is initially heavily contaminated and then sterilized through boiling, would still contain large quantities of organic compounds. If this water is recontaminated with coliforms from the hands of household residents, the organic compounds would provide favorable nutrients for bacterial growth. Households with kitchens that were judged to be clean were four times more likely to have clean water. Presumably, this attention to cleanliness, reduced the risk of recontamination of the water.

Other potential explanations of coliform contamination in drinking water reported as being boiled include, that study subjects did not accurately report whether or not they boiled their water. However, in 95% of households where respondents reported boiling, interviewers observed a cooking pot used for boiling, which had water in it 67% of the time, so reporting appears to be accurate. Laboratory error could produce anomalous results, but the methods used were standard, and laboratory errors generating haphazard results, would not be expected to produce the observed association between clean water and clean kitchens. Coliform organisms resistant to

Table 4. Water Storage Vessels, Indicators of Income, and Cleanliness as Predictors of Potable Water, Karachi 1994 (n = 293*)

	Potable Water Found among Households				
Exposures	*With Disclosure n (%)*	*Without Disclosure n (%)*	*Relative Risk*	*95% CI*	*P-Value*
Observed water storage vessel†					
Earthen pot	4 (14)	13 (13)	1.1	0.4–3.0	1.0
Metal tank	4 (20)	13 (13)	1.5	0.6–4.2	0.4
Income indicators					
Reported income above median range	17 (18)	25 (14)	1.3	0.7–2.3	0.4
Crowding	5 (8)	40 (19)	0.5	0.2–1.1	0.06
Toilet crowding	8 (11)	40 (18)	0.6	0.3–1.2	0.11
Cleanliness					
Kitchen judged clean by observer	31 (23)	4 (5)	4.2	1.6–11.5	0.001

*Households for which exposure information was unavailable were excluded from the denominator; †only those households that used one method of water storage exclusively were included in this analysis. The insulated water storage vessel was the reference group to which those with earthen pots and metal tanks were compared.

boiling, would produce similar results, but the authors are not aware of such organisms being described. Thus, although the study did not directly observe or measure recontamination, it is the most likely explanation of the data. This interpretation is consistent with data from Trujillo, Peru, during a 1991 cholera epidemic in which municipal well water was consistently cleaner than tap water, which was cleaner than water stored in the household.[3] Similarly, in suburban Rangoon, Burma, water samples collected at their source were cleaner than samples from collection vessels, which were, in turn, cleaner than samples from home water storage vessels.[14]

In the setting of an intermittent water supply, urban residents have no choice but to store water. This study suggests that most of this home-purified and stored water is not safe for drinking. The optimal solution is to improve municipal water treatment and replace and expand the distribution system so that sufficient water supply and residual chlorination is continuously available in all households. However, because Karachi municipal authorities, like many developing-country mega-city governments, face severely restricted budgets, urgent competing priorities, a limited water supply, and rapid population growth, such massive capital intensive solutions are, at best, decades away. An alternative interim solution is to improve home water storage. Using storage vessels that prevent ready recontamination through a narrow neck, and home chlorination of water have been effective in improving water quality and reducing diarrhea and cholera incidence.[15-17] Because these Karachi residents were already spending considerable time and money to secure a clean water supply, efforts to improve their home water purification and storage practices may be the most cost-effective solution to improving drinking water quality in the short and intermediate term.

There are important limitations to this study. First, total coliform in drinking water was evaluated, which is a less specific marker of fecal contamination than are thermotolerant coliforms or fecal *Escherichia coli*.[11] However, the presence of total coliform in treated drinking water suggests either incomplete decontamination of source water, or recontamination of treated water, either of which puts the household at risk for waterborne diseases.

A second limitation is that these water samples were not randomly selected from the whole city throughout the year. The water samples were collected from neighborhoods where there was a confirmed case of typhoid fever, which might bias toward those areas with worse sanitary conditions. On the other hand, neighborhoods were sampled that used the laboratory facility of a private hospital, which tend to be wealthier areas, presumably with better water supply and sanitary infrastructure. On balance, the central findings of the study, that home drinking water quality was poor despite major efforts to purify it by households, is unlikely to change with a more complete sample.

Unsafe water causes substantial human disease and death. Improvements in municipal supplies and distribution systems, especially with efforts to maintain a constant water supply, are important long-term solutions to safer drinking water in cities in developing countries. In the meantime further refinements and evaluations of home-based efforts to purify and store water are needed.

ACKNOWLEDGMENTS

The authors thank Mr. Mahboob Alum, who organized the laboratory procedures, Shaista Abdullah, who performed the microbiologic testing on the water samples, and Dr. Rumina Hasan, who reviewed the manuscript.

REFERENCES

1. United Nations Development Program. Human development report 1996. New York: Oxford University Press, 1996.
2. Swerdlow DL, Mintz ED, Rodriguez M, et al. Waterborne transmission of epidemic cholera in Trujillo, Peru: lessons for a continent at risk. Lancet 1992; 340:28–33.
3. Synder JW, Mains CN, Anderson RE, Bissonnette GK. Effect of point-of-use, activated carbon filters on the bacteriologi-

cal quality of rural groundwater supplies. Appl Environ Microbiol 1995; 61:4291-4295.

4. Kirchhoff LV, McClelland KE, Do Carmo Pinho M, Araujo JG, de Sousa MA, Guerrant RL. Feasibility and efficacy of in-home water chlorination in rural northeastern Brazil. J Hyg (Lond) 1985; 94:173-180.
5. Conroy RM, Elmore-Meegan M, Joyce T, McGuigan KG, Barnes J. Solar disinfection of drinking water and diarrhoea in Maasai children: a controlled field trial. Lancet 1996; 348:1695-1697.
6. Marsh D, Husein K, Lobo M, Ali Shah M, Luby S. Verbal autopsy in Karachi slums: comparing single and multiple cause of child deaths. Health Policy and Planning 1995; 10:395-403.
7. Maxwell RJ. Learning from the Third World. Lancet 1986; 8474:222-223.
8. Luby S, Faizan M, Fisher-Hoch S, et al. Risk factors for infection with *Salmonella typhi* in an endemic setting, Karachi Pakistan. Epidemiol Infect 1998; 120:129-138.
9. Lechtman MD, Wistreich GA. Microbiology. 4th Ed. New York: Macmillan, 1984:897-898.
10. Volk WA, Wheeler MF, eds. Basic microbiology. 6th Ed. New York: Harper and Row, 1988:588-589.
11. World Health Organization. Guidelines for drinking-water quality. 2nd Ed. Geneva: World Health Organization, 1993.
12. Dean AG, Dean JA, Coulombier D, et al. Epi Info, Version 6: a word processing, database, and statistics program for epidemiology on microcomputers. Atlanta, GA: Centers for Disease Control and Prevention, 1994.
13. Karachi Development Plan 2000. KDA: master plan and environmental control development, June 1991.
14. Han AM, Khin NO, Midorkawa Y, Shwe S. Contamination of drinking water during collection and storage. Trop Geogr Med 1989; 41:138-140.
15. Quick RE, Venczel LV, Gonzalez O, et al. Narrow-mouthed water storage vessels and in situ chlorination in a Bolivian community: a simple method to improve drinking water quality. Am J Trop Med Hyg 1996; 54:511-516.
16. Quick RE, Venczel LV, Mintz ED, et al. Diarrhoea prevention in Bolivia through point-of-use water treatment and safe storage: a promising new strategy. Epidemiol Infect 1999; 122:83-90.
17. Deb BC, Sircar BK, Sengupta PG, et al. Studies on interventions to prevent eltor cholera transmission in urban slums. Bull WHO 1986; 64:127-131.