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Determinants of water quality, availability and use in Kurunegala, Sri Lanka

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Abstract

Between January 1987 and February 1988, 4590 homes of children under five years of age were visited in three areas of Kurunegala district, Sri Lanka and data were collected on water related practices. 60% of the population used protected wells, 30% used unprotected sources and 10% used handpumps on boreholes or piped supplies. 90% of households had a source less than 1 km away. Mean water consumption was above 25 litres per capita per day and did not correlate with the distance to source. Samples of drinking water were collected and faecal coliform levels were determined in samples of stored water from 3092 households and in samples from the water sources used by 1043 of these households. The absence or presence of organisms in each sample, and the geometric mean count in samples with organisms were used as indices of contamination. Both indices changed with season and varied between areas and between types of water source. The proportion of positive source samples was uniformly high with the exception of piped supplies and handpumps. The mean count was highest for unprotected sources. There was no evidence that ground water contamination occurred in boreholes. With stored samples, boiling appeared to reduce contamination markedly. The proportion of positive stored water samples was also lower with the use of different vessels for collection and storage, with storage inside the house, and with use of a storage container other than an earthenware pot. Because surface water pollution appears to be important it is proposed that headwalls and drainage aprons be built around unprotected sources. Faecal contamination at the source may have more public health significance than contamination of stored water. In this respect public hygiene may play an important role in reducing water pollution at handpumps or protected wells.

Introduction

Factors that determine the pollution of water or its availability in rural areas of the developing world are of major interest to planners of water supplies. In the last two decades it has become increasingly apparent that, far from being uniform, the conditions necessary for the successful im-

plementation of water supply programmes vary with geographical and sociocultural differences (Schneider et al., 1978). Many of those who work to improve rural water supplies in developing countries have broadened their interest from the technical and economic field to adopt a more comprehensive approach taking fuller account of the water user's physical and cultural environment.

Water is closely bound up with the lives and health of people. It is thus a complex task to predict the benefits that might be expected from the improvement of water sources which, in developing countries, are often scarce or unsuitable. Improved water supplies can benefit a rural population in a variety of ways. Health benefits in particular can result indirectly from time savings (Cairncross and Cliff, 1987) as well as directly from changes in hygiene practices, and the consumption of water free from pathogens and contaminants.

In rural Sri Lanka, as in many parts of the world, drinking water and water used for domestic purposes is carried home from the source and is stored in vessels until consumption. Drinking water quality can therefore be affected by contamination at the source, during the collection process and also during storage (Rajasekaran et al., 1977; Feachem et al., 1978). There may be dramatic changes in the content of pathogens during this process, for example if the water is boiled.

This paper presents the results of an investigation of water quality, water consumption and water source choice which formed part of a larger study of paediatric diarrhoeal disease in Kurunegala, Sri Lanka.

Materials and methods

Study population

The study area had a population of approximately 360,000 inhabitants and has been described elsewhere (Mertens et al., 1990a).

The samples of drinking water were collected at the households of the children aged less than five years who had been recruited in a case-control study of diarrhoea and in cross-sectional surveys. Three distinct groups of children were included; children reporting to clinics with diarrhoea (cases), children reporting to clinics with complaints unrelated to water supply and sanitation (clinic controls) and children selected at random from the community (community controls). Details of the selection of children are given in the third paper of this series (Mertens et al., 1990b).

For children recruited at clinics the sample of drinking water was, on average, collected one week after the child's disease. The subsample of cases and clinic-based controls whose homes were to

be visited were selected at random every week and an average of 40 visits were performed per week between January 1987 and February 1988. A water sampling visit was carried out for the community controls at the time of cross-sectional surveys in the same catchment areas covered by the recruiting hospitals. Since faecal contamination of drinking water quality may change during the collection and storage process (Rajasekaran et al., 1977; Feachem et al., 1978), samples were collected not only from public and private sources but also from household water storage vessels. At the house the water stored for drinking was sampled and in every third household water was also sampled directly from the source.

Household interviews and observations

Two separate home visits were conducted for the children recruited at hospitals. One for the collection of water specimens and assessment of the water quality and one where information on water source choice and water consumption was collected (Mertens et al., 1990a). In the community, one single visit was made at home in three different areas. Mothers were interviewed about their choice of drinking water source and whether a different source was used for other household purposes. The household was also asked to estimate the time required for a return journey to each source, and the result checked by walking the distance. An estimate of the household's overall water consumption was made by asking how many water collection journeys were made on an average day, and by estimating volume of the vessel normally used. The result was expressed in litres per capita per day (l. c.d.). Additional questions were asked relating to hygiene practices and socio-economic factors.

Environmental microbiology

All samples were collected in sterilised glass and plastic bottles using standard procedures (Cheesbrough, 1984; WHO, 1984). In order to assess the quality of the water that people usually drink, no sterilisation of the mouth of a tubewell or of the collecting bucket for shallow wells or the storage vessel was carried out. In addition, 60 samples of tubewell water were taken after sterilising the mouth of the pump in order to assess the quality of the ground water. Bottles were transported in coolboxes designed to maintain the temperature between 4°C and 8°C. Samples reached the laboratory within 3–6 hours of collection.

Membrane filtration was carried out for all samples using two field testing kits and several incubators. All samples were kept at 4°C. on arrival in the laboratory and were filtered and 2.5 ml of sterilised lactose culture medium (membrane lauryl sulphate broth, MLSB) were added under aseptic conditions. The inoculated culture dishes were then incubated at 44.5°C for 18 hours and examined for the presence of faecal coliforms (FC) (WHO, 1984). The number of yellow colonies present on the dish after incubation was then recorded (Cheesbrough, 1984).

The choice of either a filtration volume of 5 or 25 ml depended on the expected level of contamination, which varied with seasonal rainfall levels. At low levels of contamination, good precision in coliform counts can be obtained from either test volume but the sensitivity of the 5 ml volume is poor. However, with high levels of contamination the 25 ml volume gives poorer precision. Therefore, in the period of lower contamination (Jan to Sept 1987) all the samples were analysed using 25 ml and in periods of high contamination (which coincided with high seasonal rainfall) the samples were analysed using 5 ml. One in six of all samples for the full time period were analysed twice, using both volumes.

When a volume of 25 ml had been filtered and more than 500 colonies were counted after incubation, the count was assigned a value of 2000 faecal coliform colonies per 100 ml water. If 5 ml were filtered, and more than 500 colonies were seen, a value of 10000 faecal coliform colonies per 100 ml of water was assigned to the count. Therefore, the counts of heavily contaminated samples are censored to these upper limits.

The laboratory technician was not aware of the identity or disease status of the child or the type of water source when performing the microbiological analyses.

Quality control

Quality control checks were performed regularly using two different procedures. First, distilled sterile water in bottles labelled in such a way that they could not be recognized from other usual samples, were tested for bacteriological contamination twice a week. No colonies appeared on any of these test samples. Second, bottles containing water from the same source or vessel were labelled with different numbers and handed over to the laboratory. Counts were then compared and averaged when close agreement was reached on the counts. In eight out of 91 such samples the two counts were in complete disagreement, and the overall result was excluded from the analyses. Thirdly, the same sample was filtered twice and colonies were counted separately by two persons. There was 97% agreement between the counts.

Statistical methods

Specimens were classified by the presence or absence of faecal coliforms (FC). Among the samples with coliforms, the means of the logarithms (base 10) of the counts were used to give geometric mean counts. The effect of truncation of the high counts was assessed by comparing the means calculated with censored values equal to 2000 or 10,000, and the means adjusted for censoring by Wolynetz's method (1979). The proportions with faecal coliforms and the mean counts were then classified by the factors of interest, such as source, season, and boiling. To explore the combined effects of several factors on water quality, regression methods were used. First, the proportion of positive specimens was used as dependent variable in logistic regression models. Second, the log count among positive specimens was used as dependent variable in ordinary least squares regression. Statements of statistical significance are based on chi-square and t-tests and on the results of fitting the regression models. In the logistic regressions, where a greater variability than expected from the binomial distribution occurred, the test statistics were adjusted by the dispersion parameter, estimated from the Pearson chi-square (McCullagh and Nelder, 1983).

Results

Number of water samples collected and analyzed

Between 21 January 1987 and 26 February 1988, a total of 4590 children under five years were visited at home in Maho, Nikaweritiya and Wariyapola areas and data were collected on water related practices. In the same areas plus in Kurunegala area, 3185 samples of stored water and 1521 samples of source water were collected and analyzed for evidence of faecal contamination from the home of 856 cases of diarrhoea, 1406 clinic-based controls and 923 community-based controls. For 93 of the samples of stored water (2.9%) and 118 (7.8%) of the samples of source water, the results of these microbiological analyses were inconclusive. These samples are therefore excluded from the following analyses. For 85 (2.7%) stored and 108 (7.1%) source water samples the colonies were too numerous to count and were allocated the minimum values of 2000 or 10,000 faecal coliform colonies per 100 ml of water according to whether the volume of water filtered was 25 ml or 5 ml. In a few cases, the information on type of source or water storage practice was not available. On average, data were missing for 2% of the samples for each variable. Thus numbers vary slightly, depending on the variable under consideration.

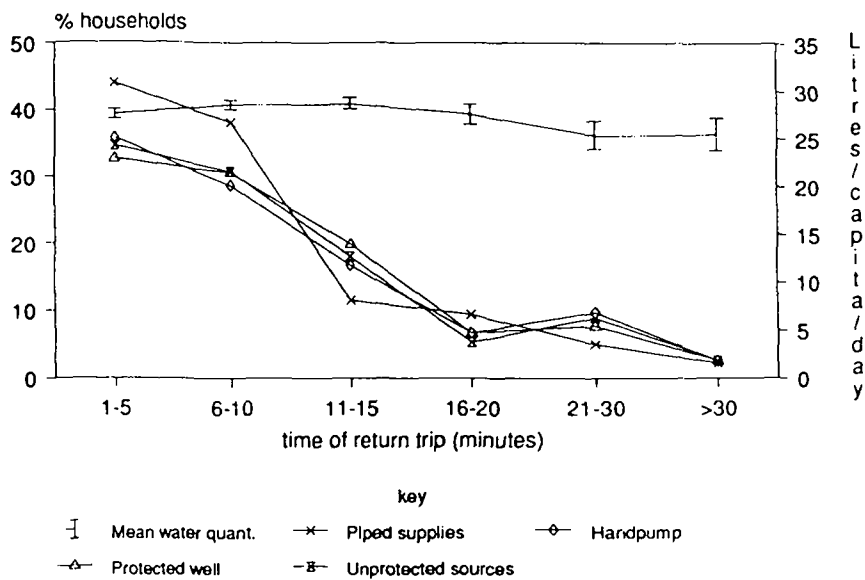


Fig. 1 Travel time to sources and mean water consumption of 4439 households, Sri Lanka 1987-88

Water source choice and water consumption

Several types of water source were used for drinking. The most common, used by 60% of households, was protected shallow wells, sometimes 10 or more metres deep. These were lined with masonry or concrete, with a protective parapet and apron, and water was drawn from them by bucket. A further third (30.8%) used unprotected sources, usually wells or waterholes, unlined and often less than two metres deep, but sometimes surface water from rivers, irrigation channels and large open reservoirs known as tanks. Only a small minority (6.0%) used handpumps, mostly installed on boreholes. The boreholes with handpumps were in the course of installation in the northern part of the district of Kurunegala during the study, as part of the integrated rural water supply and sanitation programme started there in 1986 by the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ). By December 1987, as the study neared its conclusion, a total of 261 such pumps were functioning and being used by the population. Finally, an even smaller group (3.3%), who lived in small towns used piped water from public standpipes or, in rare instances, from private taps. In Wariyapola no boreholes were drilled by the GTZ but a few handpumps, installed either on boreholes or, rarely, on shallow wells are scattered in the area.

The sources used by households vary with the seasons, as some traditional sources dry up between May and September. Some wells provide water only intermittently during the dry season after brief periods of occasional rain. The data collected refer to each household's water use at the time of interview, but since interviewing continued through a full year the results reflect a typical year-round picture.

The findings reflect how even Kurunegala District, on the margins of Sri Lanka's "dry zone", is blessed with an abundance of water sources. Figure 1 illustrates that one third of all households were able to collect a container of water in five minutes or less, indicating that their drinking water sources were less than 200 metres from their homes and more

than 90% of households had a source of drinking water less than 1 km away. On average, the mean water consumption was above 25 litres per capita per day with only 7.1% of the households using less than 10 litres per capita per day.

Nearly three quarters of the population (72.7%) used only a single source for all domestic purposes, and fewer than one in five (18.3%) regularly used a separate source for purposes other than drinking; the remainder used another source occasionally. An interesting finding was that women regularly using separate sources were slightly more likely to claim that they washed their hands before preparing a meal (23.8% versus 20.4%, $X^2 = 4.7$, $p < 0.05$).

Of those using separate sources, more than half (53.4%) had to walk at least a further five minutes to obtain drinking water, and half of these walked an additional 10 minutes or more. Households using a separate drinking water source were no more likely than others to use handpump or piped water for this purpose, but a slightly greater proportion used protected wells as opposed to unprotected sources. This finding corresponded with the general view that taste was a major factor in the choice of drinking water source, and that the taste of water from existing protected wells was rated highly.

Except for households using piped supplies, which used larger quantities of water than all the others, there was no significant association between the type of water source or the distance to it and the level of domestic water consumption (Figure-1). Nor was water consumption significantly related to the education of the child's parents.

Water quality

Source water: The distribution of faecal coliform counts according to type of water source are shown in Figure 2. The percentage of samples with organisms found ranged from 48% for handpump to 82% for piped water and 95% for other sources. The counts in positives are symmetrically distributed on the logarithmic scale; this was confirmed

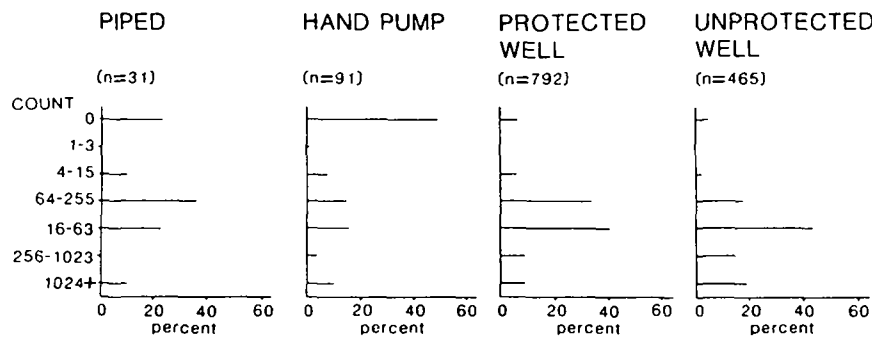


Fig. 2 Faecal coliform counts in specimens of source water

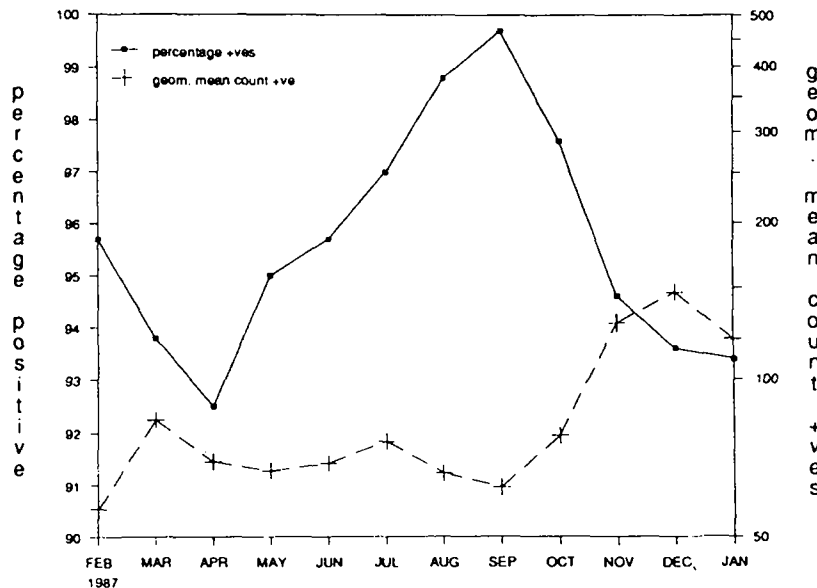


Fig. 3 Monthly trend of contamination in source water, Sri Lanka 1987. 3-point moving average of fitted percentages positive and geometric means among positives in protected wells at Maho

on more detailed inspection with the only noticeable departure arising from the censoring at counts of 2000 and 10000. Percentages of samples positive and geometric mean counts among positives were taken as separate measures of contamination. Correction for censoring carried out using data from source and stored samples, classified by type of source and by boiling, suggested that geometric means based on the censored data were underestimated by only 2% to 5%. Therefore, no correction for censoring was applied in the following analyses.

The trends over time of the two measures in source samples are shown as three-point moving averages, adjusted for place and source differences, in Figure 3. This figure indicates the general trends, on average for all five places, using as a baseline the faecal contamination levels found in Maho, where water analysis was carried out all year round; they do not indicate any trends at Maho that are different from the other places. The most marked feature was the rise in mean faecal coliform counts at the end of the year, to a peak in December (during the north-east monsoon). The first determination of the mean count (January 1987) was low, possibly because drought conditions had prevailed in late 1986 and early 1987. In September, 1987 there was an opposite trend between the geometric mean faecal coliform (GMFC) count and the percentage FC positives: while the percentage of positives increased the GMFC count decreased.

The two measures in source water samples, by type of source and place are given in Table 1. Percentages positive for faecal coliforms were significantly lower for piped and handpump water, compared with the other sources ($p < 0.01$). Mean counts were higher for unprotected sources ($p < 0.01$ for all three comparisons) but showed no significant differences among the other sources. Specimens from Maho and Ambanpola tended to be less frequently positive than the others. Mean counts were lower in Kurunegala and Wariyapola than in Maho and Nikaweritiya ($p < 0.02$) and higher in Ambanpola ($p < 0.01$).

In order to establish whether contamination recorded for handpumps was related to ground water pollution, 60 tubewells equipped with handpumps and used by the study population were sampled after sterilising the mouth of the pump. These samples were taken and analysed for five consecutive months from November 1987 to March 1988. The laboratory technician was kept blind to the origin of those samples. The results of these analyses indicate that out of a total of 216 samples, organisms were found in only ten (4.6%). These positive counts were in samples from nine different tubewells, each of which was sampled a minimum of three consecutive times. Furthermore, amongst the positive counts only once a value of more than 150 faecal coliform colonies per 100 ml and twice a value of more than 50 faecal coliform colonies per 100 ml was recorded.

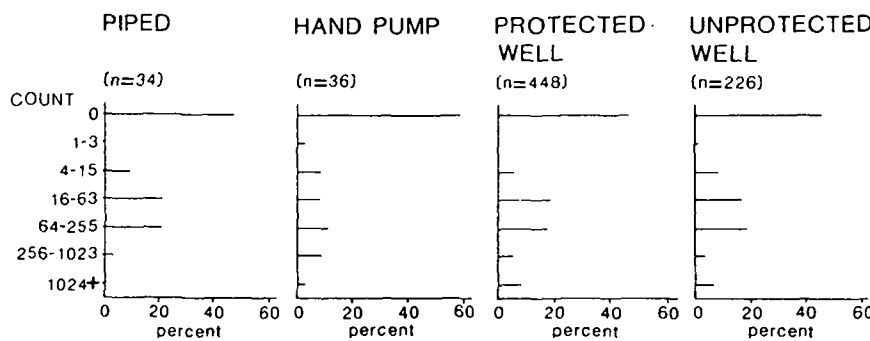


Fig. 4a Faecal coliform counts in specimens of stored water (water boiled)

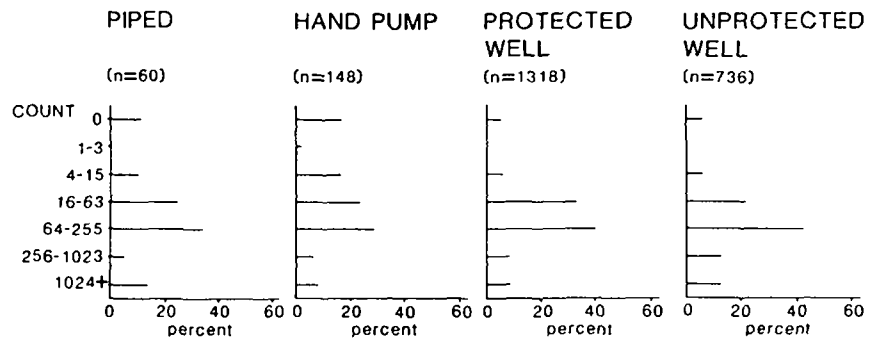


Fig. 4b Faecal coliform counts in specimens of stored water (water not boiled)

Table 1 Percentage of source specimens with faecal coliforms found, and geometric mean (GM) count for those with coliforms found, by source and place

Place			Piped Supply	Handpump	Protected well	Unprotected source
Maho	Proportion + ve		5/6 83%	5/25 20%	233/249 94%	127/135 94%
	GM among + ves				100	224
Nikaweritiya	Proportion + ve		1/2	26/31 84%	147/155 95%	81/86 94%
	GM among + ves			122	105	199
Kurunegala	Proportion + ve		2/2	2/4	175/180 97%	99/103 96%
	GM among + ves				84	136
Wariyapola	Proportion + ve		15/17 88%	13/14 93%	155/1599 7%	75/79 95%
	GM among + ves		75	68	74	148
Ambanpola	Proportion + ve		1/4	1/17 6%	43/4890%	61/62 98%
	GM among + ves				154	484
Total	Proportions + ve		23/31 77%	47/91 52%	753/791 95%	443/465 98%
	GM among + ves		62	96	93	203

Stored water: When drinking water was stored separately from water for other purposes samples were always collected from the pot in which water for drinking was stored.

Stored water samples showed similar trends over time in faecal contamination as were seen for source water (Figure 3).

Figures 4a and 4b show faecal coliform counts in stored water samples. The separation between negatives and positives is again clear, as is the effect of boiling. Table 2 gives the numbers and percentages of samples boiled and not boiled, by source and by place, with the percentages positive and the mean counts. The proportion of households which boiled water was greater among users of piped supplies. The benefit of boiling is more apparent in the percentages positive than in the mean counts. The difference in quality of water from piped supplies and handpumps, or from protected sup-

plies in general, seems to be only partly preserved in the process of carrying and storage unless the water is boiled.

Comparison between source and stored water: 1306 (93%) of 1403 source water samples included in the analysis were paired with stored samples from households using the same source. Figure 5 illustrates the relationship between the counts on a pairwise basis, for all sources. The rarity of low non-zero counts and the appreciable number of pairs where one sample is negative and the other positive should be noted. The effect of boiling is also clear.

Table 3 shows, for each source, the classification of the pairs by the finding of organisms in the two samples. Among boiled samples, the high proportion showing a change from a positive sample at source to a negative sample from the stored water is striking. Among samples claimed to be unboiled, the highest proportion of negative stored samples

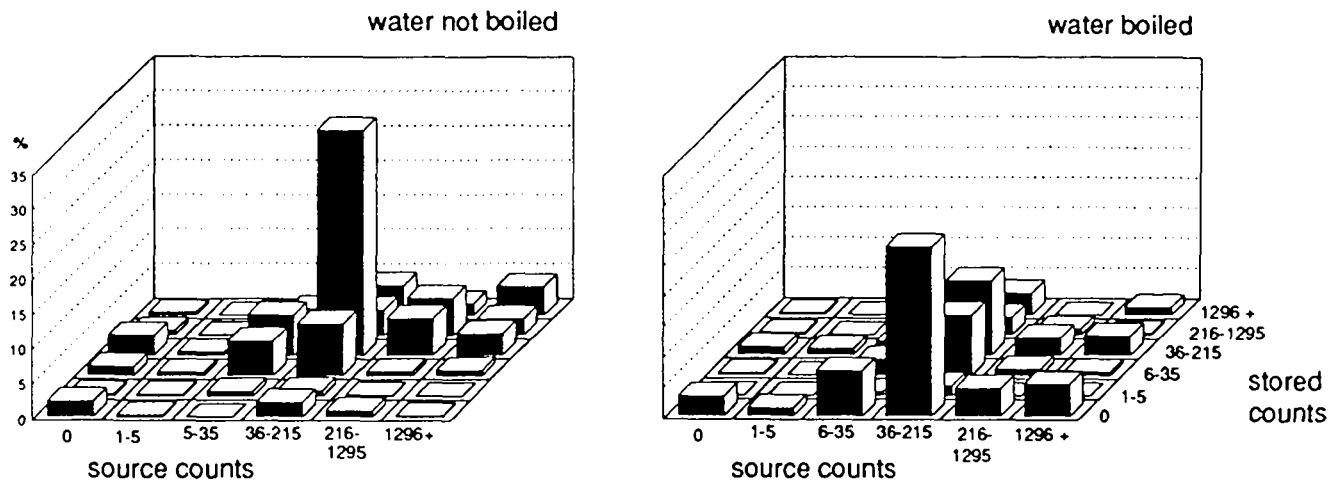


Fig. 5 Comparison of paired specimens of source and stored water: effect of boiling the water on faecal contamination

Table 2 Samples of stored water, classified by source and whether it was claimed to be boiled or not, with percentages positive for faecal coliforms, geometric mean (GM) counts among the positive specimens and confidence intervals* (CI) on the geometric means.

	Piped supply	Handpump	Protected well	Unprotected source
Boiled				
no. specimens	34	36	448	226
percent + ve	53%	42%	53%	54%
GM among + ves	52	55	103	71
95% CI	24-110	24-126	84-127	53-95
Not boiled				
no. specimens	60	148	1317	736
percent + ve	88%	83%	94%	94%
GM among + ves	99	64	101	144
95% CI	63-154	48-86	92-111	128-163

*The confidence intervals are based on the within-cell variance of the log counts.

paired with negative source sample was from handpumps. Among handpump samples however, a substantial proportion of the pairs changed from negative at source to positive when stored. Conditional logistic regression analysis of the discordant pairs confirmed a strong boiling effect ($p < 0.001$), and among unboiled samples a strong contrast between handpump water quality compared with protected wells and unprotected sources ($p < 0.001$).

Other factors affecting stored water quality: As shown above, among households where the respondent claimed that the water was boiled, the percentage of positive samples as well as the average level of contamination in the samples were much lower compared with samples taken from other households. Among unboiled samples the water was less frequently contaminated and the level of contamination among positives was lower if it had been drawn from a handpump.

The following additional factors were associated with lower levels of contamination in stored water:

- Use of different vessels for collection and storage. Among boiled specimens, 43% of the samples were contaminated compared with 57% when the same vessel was used. Without boiling, the figures were 84% and 94%. Not surprisingly, use of a different vessel was more common when the water was boiled, at 37% compared with 3% without boiling.

- Storage inside the house. With water from unprotected sources, 96% of specimens from outside storage were contaminated, compared with 83% from storage inside. The most common storage arrangement was inside with a cover; 87% of boiled and 75% of unboiled specimens came from water stored this way. There was no evidence that failure to use a cover was associated with contamination, though very few households stored water outside, uncovered.

- Use of non-earthenware container for storage. 58% of samples were from earthenware vessels. Most of the rest were from larger-sized metal or plastic container and contamination was marginally less in these. A few (126) samples were from a variety of other types of vessel, such as bottles, kettles etc., and coliforms were found in these about 15% less frequently. Most of the samples in the last group were boiled, but the differences in contamination held for both boiled and unboiled water.

- Storage for a longer period, for unboiled water. When the same vessel was used (see above) and was covered during storage, there was slightly lower contamination (about 4% less positives) in specimens that had been collected more than 12 hours before sampling, compared with those collected more recently.

Table 3 Paired specimens, cross-classified by positive or negative for faecal coliforms in source and stored water specimens

Water	boiled	stored	Water source							
			piped supply		handpump		protected well		unprotected source	
			-ve	+ve	-ve	+ve	-ve	+ve	-ve	+ve
Yes	Source	-ve	1	0	2	2	4	2	3	3
		+ve	4	3	5	3	87	89	43	53
No	Source	-ve	2	2	13	18	4	24	3	12
		+ve	1	15	3	35	27	494	14	300

Table 4 Model-based estimates of percentage of specimens with faecal coliforms for water handled and stored in different manners.

Handling and storage		Water source			
		piped supply	handpump	protected well	unprotected source
Good	% +ve	32%	20%	40%	39%
Middle	% +ve	38%	38%	56%	82%
Poor	% +ve	87%	87%	93%	98%

"Good" - boiled, different vessel for storage, stored inside; "Middle" - not boiled, different vessel for storage, stored inside; "Poor" - not boiled, same vessel for storage, stored outside.

The overall contribution of four factors together, source, boiling, use of the same vessel and manner of storage, on the presence of faecal contamination in the samples of stored water was explored by logistic regression. Apart from source, the order of importance of the factors was boiling, use of different vessel for storage, and storage inside; storage inside was statistically significant only for water from unprotected sources. The model also indicated that samples from the community surveys were less often contaminated. Table 4 shows predicted proportions of samples contaminated when categorized in what appeared to be the good, middle and poor ways. The good and poor ways were adopted by relatively few households in this survey; 9% were in the "good" category and 11% in the "poor" (4% and 10% respectively among users of handpumps). The table indicates the extremes of what might be achieved, with percentage ranging from 30% to 98%, under the assumptions of the model.

We found no evidence that the time of the day at which the collection took place or the time taken to carry out the water collection had any effect on stored water quality.

Discussion

On average, mean water consumption was above 25 litres per capita per day and was unrelated to the type of source or the distance to it or the education of the child's parent. Although it is, perhaps, a counterintuitive finding, this corresponds with the results of studies elsewhere in the developing world (White et al., 1972; Feachem et al., 1978), and in Sri Lanka (Pinnawala and Herath, 1986). Even during the drought the time to reach a source of water did not differ substantially from normal conditions, except for a minority of the households.

Environmental microbiology was performed using the membrane filtration technique, which is well standardized and yields sensitive and specific results (Cheesbrough, 1984; WHO, 1984). Quality control checks confirmed to some

extent the reliability of the method in this tropical setting with 97% agreement between different filtrations of the same sample, 8.8% disagreement between samples of the same origin and 100% specificity on sterile water.

In this study the level of faecal contamination occurring at the water source appeared to depend on the type of source, rainfall and, to a lesser extent, on geographical location. These results confirm the findings of a number of other studies conducted in a wide variety of settings (Barrel and Rowland, 1979; Wright, 1986; Blum et al., 1987).

In general, the proportion of samples in which FC colonies were found, and the level of contamination of water as measured by the geometric mean FC count were both very high in comparison to WHO Guidelines for Drinking Water Quality (WHO, 1984). The sources which provided drinking water closest to these standards were public handpumps first, followed by the piped supplies. Handpumps provided water of the best quality throughout the year. When the mouth of the tap was sterilised less than 5% of samples showed faecal contamination at low levels. However, when water was drawn in the usual manner around 50% of samples were found to be contaminated. These results suggest that ground water contamination is negligible if it occurs at all, but that substantial pollution of water occurs at the periphery of the system. Public handpumps are the site of intensive human and animal activity and both animal and human contamination of the mouth of the tubewell probably occurs, particularly via contaminated hands. Amongst the 50% of samples which showed evidence of faecal contamination, the average level of pollution was as high as the mean level in polluted samples from protected shallow wells.

Protected wells are a traditional source of drinking water in Sri Lanka; they are widely used by more than 50% of the population and are regarded as providing water which is "tasty" and pure. About 45% of these wells are public and were dug by the government. Unprotected sources include

shallow water holes, usually owned privately and surface water. The water provided by these sources revealed high levels of contamination in 96% of the samples tested.

There were seasonal variations in the level of pollution, especially in water drawn from the traditional sources, including protected wells. The geometric mean of faecal coliform counts peaked in December during the monsoon rain whereas the proportion of positives peaked earlier, at the beginning of the rain in September. Pollution which peaks during the early rain is usually attributed to run-off and is most likely to affect unprotected water holes. Contamination of traditional sources, however, lasted until long after monsoon rain had stopped in 1987, especially in unprotected sources. Anthropological investigations in Sri Lanka suggest that this seasonal pattern of water pollution is common knowledge (Nichter, 1988).

This seasonal pattern suggests that surface water pollution has a more important effect than ground water pollution on the quality of water provided by unprotected water sources. This has important policy implications, since it suggests that water quality could be greatly improved simply by the construction of a protective headwall and drainage apron around the unprotected sources which are used by approximately one third of the population.

The factors that strongly influenced the quality of stored drinking water were (i) the type of source from which it was drawn, (ii) whether or not the household claimed to boil the water, and (iii) the method of storage. Whether or not the water was claimed to be boiled appeared to be the most important modifier of stored water quality although boiling was practised by only 25% of the population using handpumps and traditional sources and 35% of piped supply users. While it may not seem surprising that boiling affects water quality, this finding helps to confirm the accuracy of the information given by the respondents during the interview. However, about 50% of the samples were still positive after boiling, probably because water was often allowed to cool in a vessel for several hours before consumption.

For unboiled samples, the contamination of stored water was similar to that of the source water except for the unprotected sources where storage appeared to have decreased the level of contamination. The effect of the type of source on the proportion of sample of stored water which were contaminated may be summarised in the following way. Among those who boiled or stored the water inside the house and used a different vessel for storing purposes, the proportion of samples contaminated from handpump was much less than that of all *protected* and unprotected traditional sources. However, if the water was kept unboiled, stored outside or uncovered and the same vessel was used for collection and storage, then the superiority of handpumps and piped supplies over the protected wells was much reduced, but remained substantial over the unprotected sources.

The results presented above suggest that, while improved sources suffer lower levels of faecal contamination, this effect is reduced when the water is stored. However, the microbiological analyses performed provide information only on *indicators* of faecal contamination. They tell us little about

the level of contamination with enteropathogens. It might reasonably be argued that it is contamination of water at the source which is most important in the transmission of diarrhoeal diseases (Feachem et al, 1978). At any given time, contamination of water within the household is unlikely to lead to infection with enteropathogens unless a household member is already infected. Moreover, pathogens present in the household are likely to be transmitted between the household members anyway, by other routes. Source water, on the other hand, may be exposed to contamination by a much larger population, especially when the source is public or shared by several households, increasing the probability of contamination with pathogens leading to infection. Such a situation may well occur in the district of Kurunegala where only a small minority of households own their own well. About 50% of the population draw their drinking water from public wells while the remaining 40% of the population depend on facilities owned by other people for drinking water (Pinawala and Herath, 1986). Thus changes in the pathogen content of water during its collection, transport and storage (without boiling) may depend upon differences in the survival characteristics of each pathogen present. Indicators of faecal contamination may not truly represent the presence of enteropathogens in the water since domestic faecal contamination with normal intestinal flora can still occur and will be detected by the method.

In order to confirm this hypothesis, a useful addition to the technique of membrane filtration for the detection of faecal coliforms would therefore be the detection of enteropathogens, such as *Shigella* spp and *Salmonella* spp, in stored water. Such techniques require larger volumes to be filtered and special growth media, and have been used in a few studies only (e.g. Sinigre et al., 1975). This study suggested that enteropathogens such as *Salmonella* spp could be isolated from drinking water at source water which otherwise fulfilled the standards in regard to total and faecal coliform counts.

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