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Bacteriological contamination of water in rural areas: an intervention study from Malawi

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Summary

The bacteriological quality of drinking water sources and of stored household water was examined in a rural area of Malawi, before and after improvement of the method of water supply. Among the traditional water sources, water quality was better in springs than in wells and rivers. During the rainy season, there was a considerable deterioration of water quality, which was most pronounced in wells. The improved water supply system consisted of piped, untreated surface water from an uninhabited mountain area. This water contained a mean value of 54 faecal coliforms per 100 ml which can be regarded as acceptable in this setting. During collection of drinking water and during household storage, there was considerable contamination, which mirrored the unhygienic environment. Contamination was worse during the rainy season than during the dry season. Technical interventions aimed at improving water supply in rural areas of developing countries will probably not become effective unless combined with comprehensive health education programmes for the population concerned.

Introduction

An adequate supply of clean water is of invaluable importance for any community. Diarrhoeal diseases, which are a major cause of morbidity and mortality in infants and young children in developing countries, are easily spread by contaminated water (Black *et al.* 1978; Hughes *et al.* 1982; De Mol & Bosman 1978; Sadruddin *et al.* 1981; Tao *et al.* 1984). It is generally considered that traditional water sources used by people in these countries are contaminated by faecal material (Feachem 1980). To relieve this problem, many projects aimed at improving water supply for human consumption have been implemented throughout the world. It has long been recognized that contamination may occur at the water source and between 'tap and throat', which means that constructing an adequate water supply system might not be the only change that is necessary. Problems will still persist if the hygiene-related behaviour of consumers is not improved also (Feachem 1981).

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As part of a prospective study (Lindskog & Lindskog 1987) of the health impact of improved water supply and health education in a rural area of Malawi, water quality was bacteriologically analysed at various levels between sources and consumption.

Materials and methods

The investigation was conducted in the rift valley, west of Zomba Mountain, in southern Malawi. In this area, there are two seasons, a rainy season lasting from November to April, with an average rainfall between 800 mm and 1000 mm, and a dry season, from May to November, with very little precipitation. During the coolest months, June–July, the daily mean temperature is 21–23°C, and during the warmest months, October–November, the daily mean temperature is 26–29°C. In July (cool period), stored water held a temperature of 17–18°C in houses and 21–22°C outside in the shade. These values were probably higher during warmer periods.

The study area, which is situated 0.5–2 km from the escarpment of the Zomba Mountain, is crossed by several streams and rivers, even during the dry season. Traditionally, rivers, unprotected wells and springs are used as sources of household water.

In September 1984, an intervention programme consisting of the construction of a piped water supply system was started in the area. The source for this system is surface water from an uninhabited mountainous catchment area. The untreated water passes through a screening tank and a sedimentation tank and is then conducted through pipes by gravity to the population living in lower areas. In the villages, the water is delivered through public taps; the maximum distance to each household is to be 400 m. The details of this programme have been described previously (Lindskog & Lindskog 1987).

Water samples were taken from traditional water sources (wells, rivers and springs), from piped water and from stored household water. The number of samples from each type of traditional source was taken in proportion to the number of people using each type. Samples were taken during two dry seasons (in September 1983, the peak of the dry season, and in May 1985, the beginning of the dry season) and during two rainy seasons (December 1983–January 1984 and December 1984–January 1985). For the samples taken in May 1985, which consisted of household water collected from the piped water supply, it was recorded whether the household water was stored inside or outside the house, whether the container was covered or uncovered, and if the same container was used for both drawing and storing the water.

The sterile bottles used for taking water samples were filled by submersing them in the traditional water source or by holding them under the tap of a water pipe. For household water, sample bottles were filled with water taken from the storage containers by the same vessels usually used by members of the household; understandably, it was impossible to submerge the bottle in the container. The samples were transported to the laboratory in a cooler containing ice. Most of the samples were cultured within 6 h, at the most 10 h, after collection.

The samples were analysed for indicator bacteria (i.e., total coliforms, faecal coliforms and faecal streptococci) with the membrane filtration method (Geldreich 1975). They were cultured for total coliforms on LES endomedium (Difco) and incubated for 24 h at 37°C, for faecal coliforms on MFC medium (Difco) and incubated for 24 h at 44.5°C, and for faecal streptococci on m-Enterococcus Selective Agar (Merck) and incubated for 48 h at 37°C.

Logarithms of bacterial counts were used in order to obtain values closer to normal distribution. Bacterial counts were compared by using Student's *t*-test. Analysis of variance was applied to compare household water with the corresponding water source. Linear regression analysis was used to examine correlations between contamination of household water and environmental factors.

Results

The log values of bacteriological counts of the samples from traditional water sources used before introduction of a piped water system, are shown in Table 1. During the dry season, the faecal coliform counts of river water was higher than that of wells, while spring water tended to be better. During the rainy season, water quality was generally much poorer than during the dry season; the mean of the log values of all three indicator bacteria for the total number of samples increased significantly ($P<0.001$). The increase was higher for wells than for springs. Only total and faecal coliforms of river water showed no statistically significant differences when comparing counts for the two seasons. Results from analyses of piped water are shown in Table 1 and Figure 1; in no sample was the faecal coliform count zero, but the geometric mean of 54 faecal coliforms per 100 ml ($\log_{10}$ 1.7) was only surpassed by counts for spring water during the dry season. The standard deviation of the counts for piped water was also smaller than that of traditional water sources.

Table 1. Bacteriological water quality of traditional water sources during a dry season (September 1983), and a rainy season (December 1983–January 1984), and of piped water at the beginning of a dry season (May 1985) and during a rainy season (December 1983–January 1984)

Type of water source and season	Number of samples	Total coliforms Log_{10} (counts per 100 ml)		Faecal coliforms Log_{10} (counts per 100 ml)		Faecal streptococci Log_{10} (counts per 100 ml)	
		Mean	s.d.	Mean	s.d.	Mean	s.d.
Dry season, wells	59	2.9	0.7	2.0	1.2	2.2	0.8
Wet season, wells	65	3.7	0.9	2.9	1.1	3.0	0.9
Dry season, rivers	19	2.9	0.8	2.9	0.5	2.1	0.7
Wet season, rivers	12	3.3	0.6	2.9	0.7	3.0	0.8
Dry season, springs	26	2.4	0.5	1.6	1.2	1.9	0.5
Wet season, springs	38	2.9	0.8	2.1	0.7	2.5	0.7
Dry season, total	104	2.7	0.8	2.1	1.1	2.1	0.7
Wet season, total	115	3.4	0.9	2.6	1.0	2.9	0.9
Dry season, piped w.	40	—	—	1.7	0.4	2.0	0.2
Wet season, piped w.	10	2.8	0.2	2.2	0.6	2.7	0.2

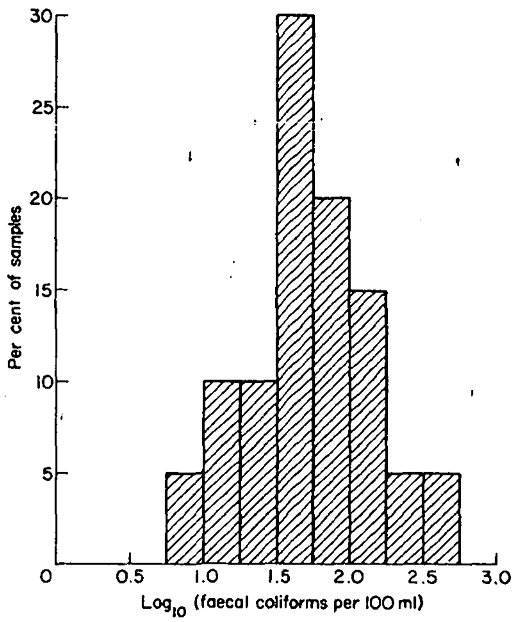

Figure 1. Distribution of faecal coliform counts in piped water taken from taps in May 1985 ($n = 40$).

The results of the analyses of 62 samples taken from containers of household drinking water, originating from traditional sources, are shown in Table 2. Some contamination occurred during collection and storage, as was shown by higher bacterial counts for household water samples compared to the counts for water samples collected from the corresponding water sources at the same time. The difference was significant only for faecal streptococci ($P < 0.001$), while there was only a tendency for total and faecal coliforms. A statistically significant correlation between the quality of household water and water at the source was obtained by analysis of variance (Table 3).

Samples of household water originating from the piped water system were analysed (Table 2). Only three of the samples had a faecal coliform count equal to zero, while 69 out of 203 samples (34%) had a count equal to or lower than that of water coming directly from a tap (Fig. 2). In most cases, however, household water was considerably contaminated between tap and consumption. The mean difference of log values of faecal coliforms in household water samples taken during the dry season and the value of the corresponding tap water samples was 0.7 ($P < 0.001$) and the difference of faecal streptococci 0.6 ($P < 0.001$). During the rainy season, almost the same difference was found between household water and tap water. The mean coliform counts varied with varying household storage conditions. There were significantly lower bacterial counts when the same container was used for both collection and storage of the water, than if separate containers were used for those purposes (Table 4). Whether a container

Table 2. Bacteriological water quality of stored household water origination from traditional water sources (September 1983) and from piped water (December 1983 and May 1985)

Type of water source and season	Number of samples	Total coliforms Log_{10} (counts per 100 ml)		Faecal coliforms Log_{10} (counts per 100 ml)		Faecal streptococci Log_{10} (counts per 100 ml)	
		Mean	s.d.	Mean	s.d.	Mean	s.d.
Dry season, traditional							
Wells	32	3.2	0.7	2.2	0.9	2.8	0.7
Rivers	13	3.3	0.6	2.9	0.8	2.8	0.4
Springs	17	2.7	1.1	1.7	1.6	2.2	0.8
Total	62	3.1	0.8	2.2	1.2	2.6	0.7
Rainy season, piped water	43	3.5	0.7	2.9	0.8	3.2	0.5
Dry season, piped water	203	—	—	2.4	0.8	2.6	0.6

Table 3. Bacteriological quality of household water originating from traditional water sources compared to the quality of its corresponding water source

Faecal coliforms in water source Log_{10} (counts/100 ml)	Number of samples	Faecal coliforms in household water Log_{10} (counts/100 ml)		
		Mean	s.d.	
<1	7	1.2	1.7	
1–2	14	1.7	1.4	
2–3	30	2.4	0.7	
>3	11	3.2	1.0	$P<0.01$

was stored inside or outside, or if it was covered or not, did not significantly affect the contamination of the water.

Discussion

Drinking water sources are often contaminated by human and animal faeces. This is especially valid for rivers, and even for wells. Rivers are commonly used for washing clothes, including napkins of infants. At the site of water collection, contamination from, among other things, washing of household utensils and water containers may also occur. The intake of the piped water supply system is protected, but, since it was under construction, it was still accessible to contamination by people. Household water can be contaminated during storage, both in the house and outside, by chickens and goats, by children and also by adults.

Generally, the traditional water sources were heavily polluted throughout the study period, indicating considerable contamination by faecal material from the environment. Bacterial counts similar to those in the present study have been found in other parts of Malawi (Lewis & Chilton 1984). From studies in other countries, considerable contamination of traditional water sources have also been reported (Adesiyun *et al.* 1983; Stenström & de Jong 1985).

Quality varied among the traditional water sources; springs were generally best. This is easily explained, since spring water is collected at the point where it is emitted from an underground source. The quality of well water was better than river water during the dry season but was more similar during the rainy season.

Water quality deteriorated greatly during the rainy season, especially in wells. This increased pollution can probably be explained by faeces

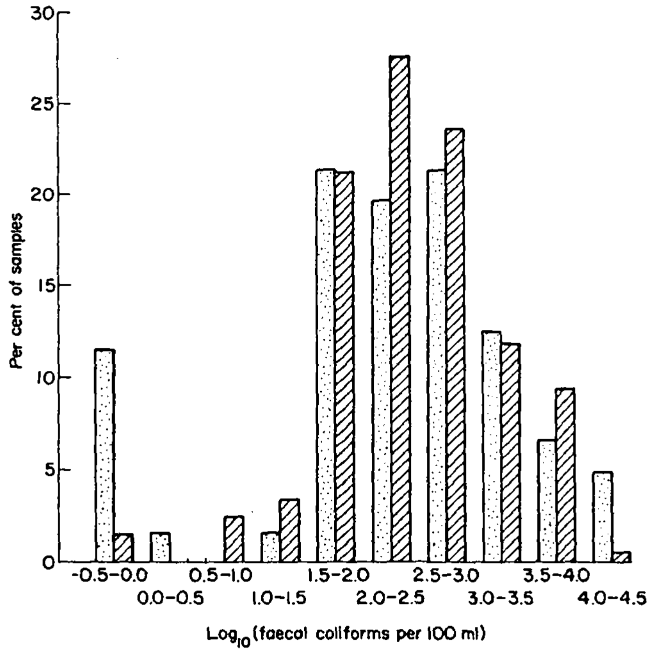

Figure 2. Distribution of water samples from households using traditional water sources (September 1983, $n = 62$) and piped water (May 1985, $n = 203$). (▒) Traditional water sources; (▨) piped water.

Table 4. Bacteriological quality of piped household water when using the same or separate containers for collecting and storing water (May 1985)

Use of container	Number of samples	Faecal coliforms Log_{10} (counts/100 ml) Mean	s.d.	
Same container	113	2.3	0.8	
Separate containers	76	2.6	0.7	$P < 0.01$

and other types of contaminating material being washed down into water sources during heavy rains. This course of events has also been observed in studies from Nigeria (Sefe, unpublished paper 1984) and Sierra Leone (Wright 1986). The water levels of rivers rose substantially during the rainy seasons, probably resulting in a dilution of contaminating materials. Water levels in wells also increased, but not to the same degree as the pollution. In a study of the relationship between rainfall and well water pollution in a Gambian village, a massive increase of bacterial counts was found to be associated with the onset of the rains (Barrell & Rowland 1979). In Sierra Leone a gradual increase of pollution was seen during the dry season, interpreted as an increasing concentration of bacteria as water volumes decreased (Wright 1986).

The quality of piped water was, as expected, better than that of water from traditional sources, with the exception of some springs. The present examination was carried out when the piped water system was under construction, which meant that the system was still open for possible contamination, and during the rainy

Table 5. Comparison of bacterial counts from a study by Young & Briscoe in Malawi, 1986, (Y & B) and from the present study (L & L)

Sample location		Study	Faecal coliforms Log_{10} (counts/100 ml) Mean	Faecal streptococci Log_{10} (counts/100 ml) Mean
Piped water	source	Y & B	1.1	2.4
	source	L & L	1.7	2.0
	house	Y & B	1.2	3.0
	house	L & L	2.4	2.6
Unprotected wells and rivers	source	Y & B	2.7	3.6
	source	L & L	2.1	2.1
	house	Y & B	2.9	3.7
	house	L & L	2.2	2.6

season, there were problems with organic material blocking water intakes. The mean number of 54 faecal coliforms per 100 ml is far above the WHO recommendations (WHO 1983). The counts may, however, be acceptable in a social setting such as this, with limited financial resources (Feachem *et al.* 1977).

Water quality is likely to improve during storage if bacteria are not added (Tomkins *et al.* 1978), because bacteria gradually die. There is evidence, however, that growth of coliforms may occur in tropical waters because of the presence of organic material in combination with high temperatures, which may lead to an overestimation of the degree of pollution in stored water (Feachem *et al.* 1977). For traditional water sources, there was a correlation between the quality of water at the source and the quality of stored household water. This shows that the quality of the water source was important, but also that water was polluted during storage.

Analyses of samples of household water collected from the piped water supply, showed that considerable contamination occurred after collection. The levels of household contamination of the traditional and piped water are not completely comparable, since the analyses were carried out during different parts of dry seasons. September is one of the driest months, preceded by 5 months without rain, while May is the beginning of the dry season, when the environment is still relatively humid. The obvious conclusion, however, is that even when a water supply is improved, household water is still highly contaminated. Therefore, there must be factors other than the quality of water at its source, which influence the quality of water consumed. This contamination is probably related to the general contamination of the environment, which is large during the rainy season. Similar contamination of household water has been found in other studies (Schiffmann *et al.* 1978). Contamination of water at the source may cause spread of infectious agents between households, which is of great epidemiological significance, while contamination of household water during storage will spread infections within the household, where infections may spread anyway. Contamination of the immediate environment is likely to be a more important route of infection than is the contamination of water.

A study of bacteriological water quality in Malawi by Young and Briscoe (1986), showed lower faecal coliform counts than obtained in the present study, both at piped water, at the tap and in the household water, in spite of the fact that the analyses were performed during the rainy season (Table 5). The faecal streptococcus counts obtained by Young and Briscoe (1986) were higher than those presented here. The differences might be due to varying techniques for sampling and culturing.

In this study, the most important factor causing the contamination of stored water, was the use of separate containers for collection and storage. If the same container was used for both, it was always emptied and washed at the water source, where water was easily accessible, before it was filled again. If a separate container was used for storage, it was usually filled without washing. This container was also more often kept inside and covered than a container used for both collection and storage; this did not, however, prevent contamination.

The people in this area were very concerned about the quality of their drinking water, and, especially during the rainy season, they often changed from one water source to another, as perceived quality deteriorated. The general opinion of the population regarding the quality of water from different sources, usually agreed well with the results of the bacteriological examinations. This interest in water quality could be used in water-related, health education programmes. These programmes could provide the knowledge that is greatly needed for obtaining the desired effects of an improved method of water supply. The objective of such education would be to change the hygiene-related behaviour of the population. To be effective, such changes must be simple and socially acceptable. Careful washing of storage containers is crucial, and this is promoted by using the same container for collecting and for storing water. Furthermore, measures need to be taken to prevent contamination during storage.

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