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"Water quality deterioration: A study of household drinking water quality in rural Honduras"

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Abstract

There is growing awareness that drinking-water can become contaminated following its collection from communal sources such as wells and tap-stands, as well as during its storage in the home. This study evaluated the post-supply drinking-water quality in three rural Honduran communities using either a protected hand-dug well or borehole supply. Water management practices were documented as a basis for further research to improve household drinking-water quality. Membrane filtration was used to compare thermotolerant coliform levels in samples taken from community wells and household drinking-water storage containers. Over a two-year period, water quality was examined in 43 households and detailed observation made of typical collection, storage and usage practice. Substantial water quality deterioration occurred between the points of supply and consumption. Deterioration occurred regularly and frequently, and was experienced by the majority of study households. Only source water quality appeared to be a significant factor in determining household water quality. None of the storage factors examined, i.e. covering the container, type of container, the material from which the container was made, and hours stored, made any significant difference to the stored water quality. Observation of household water management shows that there are multiple points during the collection to use sequence where pollution could occur. The commonality of water management practice would be an asset in introducing appropriate intervention measures.

Introduction

Drinking-water free of pathogenic organisms is fundamental to breaking one of the principal transmission routes of infectious disease. This fact has stimulated worldwide investment in the construction of water systems that are designed to meet stringent water quality standards. In many developing countries, community water systems often consist of a single public well or stand pipe that requires water to be collected, transported, and then stored for use in the home over a period of 24 hours or more. Although such water systems can supply water of excellent quality, there is considerable potential for deterioration to occur because of the amount of handling involved between supply and consumption.

There are many studies that have observed water quality deterioration during its collection and/or storage in the home *(Rajasekaran et al, 1977; Shiffman et al, 1978; El Attar et al, 1982; Kirchhoff et al, 1985; Heinanen et al, 1988; Han et al, 1989; Molbak et al, 1989; Blum et al, 1990; Morin et al, 1990; Verweij et al, 1991; Simango et al, 1992; Swerdlow et al, 1992; Shears et al, 1995; Kaltenthaler et al, 1996; Genthe et al, 1997; Hoque et al, 1999).* The majority are studies of diverse aspects of water supply, hygiene and health issues, and are not directed specifically at water quality deterioration. Other studies begin with the premise that deterioration happens or is likely to happen, and concentrate on how to improve the quality of drinking-water consumed *(Hammad & Dirar, 1982; Empereur-Bissonnet et al, 1992; Roberts et al, 2001).* However, a few studies describe more detailed research into household water management with respect to drinking-water quality *(Feachem et al, 1978; Lindskog & Lindskog, 1988; Mertens et al, 1990; Pinfold, 1990; VanDerslice & Briscoe, 1993;*

Jagals et al, 1997; Ahmed et al, 1998). It is significant that water quality deterioration has been observed in rural and urban areas throughout Africa, Asia and Latin America. Furthermore, it has been measured in a wide variety of water supply types including: piped supplies, boreholes, hand-dug wells, and even traditional sources. Only one study has been found that did not detect any water quality deterioration *(Sutton & Mubiana, 1989)*, though others have reported finding both deterioration and improvement among distinct samples *(VanDerslice & Briscoe, 1993).*

An estimated 1.5 billion people depend on engineered water systems that require collection, transport, and storage in the home *(Trevett, 2003).* If water quality deterioration between supply and consumption is a common occurrence, representing a public health risk according to the World Health Organization, then there is good reason to understand domestic water management practices in order to develop practical guidelines for maintaining drinking-water quality through to the point of consumption *(WHO, 1997).* It may be argued that unless close attention is paid to how water is collected, stored and managed, there is a risk that inappropriate solutions will be proposed and resources wasted.

Hence the objectives of this study were twofold. Firstly, to find out if water quality deteriorates in rural Honduran communities that depend on public wells, by how much, and how often. Secondly, to document the normal practice of collection, transport, storage and usage, thus providing a conceptual framework for ongoing research aimed at understanding how to prevent water quality deterioration.

Methodology

The research was carried out in three rural villages in southern Honduras from July 1998 to March 1999, and October 1999 to August 2000. Two of the villages had approximately 65 households, the third some 40 households. The climate has distinct rainy and dry seasons; the former typically begins in May and ends in October.

The villages were selected on the following basis: believed to be representative of other villages in southern Honduras, (the researcher visited around 30 villages prior to the study and had two years experience of rural water projects in the same region); accessible by vehicle; and the type of water system, namely community wells fitted with hand pumps. The study was introduced to the village water boards as an additional activity of the Association of Honduran Water Boards (AHJASA). AHJASA is a 'grass roots' style organisation that works with member communities by providing technical support for water system management. No specific mention was made to any community member of a research project in an attempt to minimise the 'observer effect'.

Principal study activities consisted of the analysis of microbiological water quality, and detailed observation of water collection, transport and storage practices. Initially the parameters selected for measurement included: thermotolerant coliforms as an indicator of faecal contamination, pH, chlorine residual, turbidity and temperature. However, chlorine residual and turbidity measurement were discontinued at an early stage as chlorine was not used, and turbidity was invariably recorded at less than 5 NTU.

Communities were usually visited in the morning between 8am and 12pm. Three samples were taken from the community well and each of the storage containers from 4 households. The replication of samples was used in recognition that coliform organisms are unlikely to be distributed homogeneously in natural waters. The most practical sample volumes for accurately counting colony-forming units (cfu) were found to be 10ml for storage containers and hand-dug wells, and 100ml for boreholes. Disposable, pre-sterilised 10ml syringes were normally used to remove samples from the storage containers. However, the design of some containers (e.g. jerry cans) required that water was first poured into a sterile sampling beaker before using a syringe to draw a 10ml sample. A portable laboratory using membrane filtration allowed samples to be processed on site, (Oxfam-DelAgua water testing kit, Robens Centre for Public and Environmental Health, University of Surrey, UK). Samples were incubated on membrane lauryl sulphate broth at 44°C ± 0.5°C for 18 – 24 hours, and procedures followed those recommended by the Department of the Environment *(1983)*. All bright yellow colonies – the yellow appearance is characteristic of *E. coli*[1] - were counted regardless of size. The water quality results in this paper are reported in terms of cfu/100ml. As a control to ensure that the equipment was being adequately sterilised between samples, 100ml volumes of sterilised distilled water were also processed.

An extension worker from AHJASA accompanied the researcher on the first visit to each community to provide introductions to several households, and indicate the location of the wells. Additional households were incorporated into the study either by directly approaching the householder for permission or occasionally through self-

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[1] *E. coli*, a thermotolerant coliform, is the most abundant coliform organism that is normally present in human and warm-blooded animal intestine. Furthermore, they usually represent around 95% of thermotolerant coliforms *(Bartram & Pedley, 1996)*.

selection by more curious householders. The aim was to visit each household at least twice, though not necessarily on consecutive visits to the community. If it was perceived that the householder was uncomfortable with the researcher entering their home no further visits were made.

On the initial visit to each household the women were asked about water collection, storage and use. This information formed the baseline knowledge regarding typical procedures involved in domestic water management and how widely these varied between households. Questioning focused on what was used to collect and store water, how it was served, and whether it was treated in any form. On all household visits the following information was also noted:

- Type (bucket, jerry can, *tinaja*, *cántaro*), and material (plastic, clay) of drinking-water storage container from which samples were taken
- If the storage container was covered
- The method used for serving drinking-water (poured, ladled, dipped)
- Approximate time water had been collected from the source
- Relevant observations of hygiene behaviour and water usage (e.g. hand washing, presence of animals in the house, location of water containers, etc.)

As the raw [microbiological] data exhibited a very skewed distribution, they were log transformed to obtain an approximately normal distribution. Analysis of variance was then used for probability testing. The relationship between hours stored and microbiological water quality was examined with the Spearman rank correlation test.

All statistical analysis was carried out using Minitab (Release 13.1 ©2000, Minitab Inc.).

Results

Data characteristics

In total 43 households were included in the study; 26 of them used water from a hand-dug well and 17 used borehole water. The median number of household visits was 4, and 79% of study households were visited at least twice. Seven households, (16% of study sample), were visited on 10 or more occasions. This provided a measure of the regularity and frequency of water quality deterioration in an individual household. Source water was consistently better from the borehole than any of the hand-dug wells. Groundwater levels in all sources were approximately 5 to 10 metres below ground level with some seasonal variation. Although it was beyond the study terms of reference to investigate the causes of source water contamination, it was noted that the wells had similar levels of sanitary protection, namely head walls, concrete aprons and drainage. Furthermore, all sources were fitted with *Mecate* hand pumps, an improved rope and washer design.

Water quality

Table 1 shows the mean bacteriological water quality measured at source and in the household storage container. It can be seen that substantial post-supply deterioration occurs. The calculated probability values demonstrate that water quality becomes significantly worse following collection and storage. Deterioration is particularly noticeable in the case of the borehole water supply, which provided water quality that consistently exhibited zero or very low levels of pollution. It is also evident that household stored water originating from the borehole is of significantly better quality than that drawn from hand-dug wells.

Using the classification system proposed by Lloyd and Helmer *(1991)*, water quality samples have been categorised according to the magnitude of contamination (Table 2). It provides a clear illustration of the proportion of samples that moved from one grade of water quality (A to E) to another, indicating the magnitude of water quality deterioration.

For example, borehole water never exceeded grade C, and 81% of samples were recorded in grade A and B. However, 36% and 20% of household stored water drawn from the borehole was classified in grades D and E respectively. Water supplied by hand-dug wells is of much poorer quality than the borehole but nevertheless considerable deterioration still occurs. This is seen in the smaller proportion of samples in grades B and C, and the increase in grade E. Furthermore the classification conceals the fact that many households using a hand-dug well source experienced deterioration within grade D.

Household water quality varied widely on any given day (data not shown). This leads to the conclusion that the individual householder was responsible for the pollution, and not the result of an environmental condition experienced by all households. Household water quality did not improve over the study period, which suggests that any observer effect was insignificant.

Water quality deterioration was observed to be a widespread problem and was experienced at least once by 95% of all study households. Data from households that were visited on 10 or more occasions showed that water quality deterioration happened regularly and frequently. However, no consistent patterns of water quality deterioration emerged among individual households. For example, a household recorded as having poor water quality on one occasion might be found to have excellent water quality in the following analysis. Thus it was not possible to distinguish between households on the basis of 'categories' of water quality deterioration. Neither did deterioration show any relation to season or the occurrence of rainfall.

Table 3 presents a comparison of water quality according to the storage characteristic, i.e. covered and uncovered storage containers, clay and plastic containers. The data used are from study days when both covered and uncovered containers were analysed, and similarly for days with both clay and plastic containers. No significant difference in stored water quality resulted from covering the container. Neither did the material from which the storage container was made have any significant advantage in terms of better water quality. However, in the case of clay and plastic containers using hand-dug well water, the probability value is marginally outside the 95% confidence level. Another important result was the complete absence of any correlation between hours of storage and drinking-water quality.

Mean (arithmetic) water temperature in clay containers was lower than its respective source water by between 4.1 and 4.5°C. This was presumably due to evaporation off the external wall of the clay containers. A slight increase in pH was observed following storage, which is most likely explained by alkaline hydrolysis caused by a reaction between water and the clay mineral surface (P.J. Loveland, National Soil Resources Institute, Cranfield University, personal communication, 11 July 2001).

Household water management

Virtually no variation in the procedure of water collection, transport and storage was observed among the 43 study households. This may be because villages tend to be quite nucleated, and distances from houses to wells are usually in the low hundreds of metres. Consequently a single water management practice could have developed because households are situated at similar distances to the well. It was also noted that communities are essentially based on a number of extended families. For example, a community of 60 households – defined as the occupants of a single house - may consist of only 20 or so families. This is also likely to add to the establishing of a common water management practice because the family remains very central to the social structure in rural Honduras.

Water collection and transport

Several container types were used for water collection including plastic and metal buckets, plastic jerry cans, and a plastic copy of the traditional clay *cántaro*. The most popular containers were plastic buckets of around 25 litre capacity. Bucket lids were rarely brought to the well, though they were used in the home. This was in contrast to jerry cans, which in most cases were used with lids. Clay containers were not used for water collection.

On arrival at the well, containers were usually rinsed out with freshly pumped water. Buckets were often rubbed with the hand while being rinsed. After rinsing, containers were usually filled to the point of overflowing. Women normally carry the collection container home on their heads and further hand - water contact was often observed as the container was lifted on to the head. This was more often the case when buckets were used because jerry cans and *cántaros* have narrow openings, and also most have a handle (unlike most buckets). For the same reasons buckets were more vulnerable to hand - water contact on the journey home when occasionally steadied by the hand.

Water storage and use

Water is either poured into the drinking-water storage container, or scooped from the collection container using a small bowl or gourd. When drinking-water is transferred to the storage container a very common practice is to pass it through a piece of linen type material. In a separate but related study 35 of 36 households stated that they 'filtered' their drinking-water in case there were any insects or dirt in the water *(Trevett et al, 2001).*

Drinking-water is most often stored in a traditional clay container, either a *tinaja* or *cántaro*. Although the containers are very similar in appearance and volume (approximately 20 litres), water is served in two distinct ways. The *tinaja* has a wide opening that allows a cup or similar utensil to be dipped, whereas the *cántaro* has a much narrower neck that requires water to be poured. The majority of households have just one container for drinking-water and *tinajas* are preferred over any other container type. This is because of the 'cooling' effect and the ease of drawing water by dipping.

The method used for serving drinking-water was largely dependent on the type of container used. Dipping the container with a cup or occasionally a gourd was the method used in 77% of the study households. Six (14%) households poured their drinking-water, and 4 more (9%) had ladles that were used to serve water into a cup for drinking.

In the vast majority of households the drinking-water container was kept covered, usually with a saucepan lid. Out of a total of 192 household visits 88% of drinking-water containers were covered. This practice is recommended in hygiene education materials used by the Ministry of Health and several development organisations.

Hygiene in the domestic environment

General observations were made about the hygiene situation in the households. Animal faeces, particularly of chicken or duck origin were regularly seen inside the house. Other animals such as pigs were frequently seen to enter the house briefly before being driven out. In the yard it was very common to see pig and goat faeces.

On one occasion it was observed that a baby was washed and changed on a table next to the drinking-water storage container. Other households stated that babies were bathed in or outside the house. This would seem to be a relatively high-risk hygiene behaviour given that the women are responsible for water management and food preparation. It was further noted that although soap was present in many households, hand washing with soap was never seen.

Discussion

This study has provided further evidence that water quality deterioration can and does occur between the points of supply and consumption. It has been shown that it can deteriorate to the extent that it is considered grossly polluted according to the classification system proposed by Lloyd & Helmer *(1991)*. Even the relatively poor water quality supplied by the hand-dug wells shows significant deterioration following collection and storage. This suggests that ongoing pollution is outstripping the bacterial die-off reported by Tomkins et al *(1978)*. VanDerslice & Briscoe *(1993)* were surprised that 16% of their samples exhibited a net decrease in faecal coliform levels. However, this is quite plausible because aside from bacterial die-off, there is often less than perfect knowledge about water management. For example, on one occasion a woman was observed cleaning the drinking-water ladle with household bleach. This could certainly have a disinfectant effect when immersed in the *tinaja*. In another household a bottle of colloidal silver for water disinfection was being used. It had been obtained from a visiting foreign medical brigade and was not locally available.

An important finding of the research is that water quality deterioration has been shown to happen regularly and frequently. No difference in the magnitude of water quality deterioration was observed as a result of season, neither did only certain households experience deterioration. This is significant as it suggest that there exists a constant and widespread problem in the handling of water between collection and consumption resulting in poor quality drinking-water.

Stored water quality did appear to be source-dependent. Stored water that originated from the borehole was significantly better than that which came from hand-dug wells. Young & Briscoe *(1987)* also observed that stored water quality appears to be a function of source water quality. In contrast, Pinfold *(1990)* concluded that stored water quality is a function of its intended use and not source water quality. However, a specific comparison of stored drinking-water quality with its respective source water quality is not mentioned.

None of the water storage factors considered in this study had any significant effect on bacteriological water quality. For example, covering the storage container did not appear to make any difference. This observation has also been made by other studies *(Lindskog & Lindskog, 1988; Simango et al, 1992; VanDerslice & Briscoe, 1993).* Neither did the type of container appear to influence water quality, though a possible explanation may lie in the relatively small sample size. VanDerslice & Briscoe *(1993)* recorded lower faecal coliform counts from containers with taps than from those that had to be dipped. Other studies also report better water quality from containers designed to prevent hand-water contact and require that water be poured *(Hammad & Dirar, 1982; Empereur-Bissonnet et al, 1992; Roberts et al, 2001).* The comparison of water quality between plastic and clay containers produced an interesting result in the case of water supplied by hand-dug wells. Although not statistically significant, water quality in clay containers was considerably better than in plastic ones. The opposite was true of water supplied by the borehole though the sample size was small. Mertens et al *(1990)* also found that faecal coliform levels in plastic and metal containers were slightly lower than those in clay containers. It is possible that a complex relationship between the microbiological flora in source water and a biofilm on the inside of storage containers leads to different coliform survival rates.

Clay storage containers maintained water temperature at about 4.5°C lower than the mean source water temperature as a result of evaporation through the porous material and were preferred over other container types for this reason. This cooling effect has been observed elsewhere *(El Attar et al, 1982; Hammad & Dirar, 1982)*. If the introduction of an 'improved' storage container is being contemplated this could be an important factor to take into account.

No correlation was found between water quality and time in hours since collection. Simango et al *(1992)* reported a similar result. While other studies have observed a progressive increase in faecal coliform levels *(Empereur-Bissonnet et al, 1992; Swerdlow et al, 1992; Roberts et al, 2001; Feachem et al, 1978)*, Mertens et al *(1990)* noted a slight improvement when more than 12 hours had elapsed since collection. The conflicting results are probably due to methodological differences, and because they are observations of the highly variable net effect of pollution and die-off.

Conclusion

The question of what causes water quality to deteriorate has not been the subject of this paper. However, detailed observations made of household water management will be developed into a set of hypotheses to be tested in ongoing research. It is clear that there are a great number of points in the sequence of collection, transport, storage and use during which contamination could be introduced. Hands, containers, dippers, 'filter' cloths, dust, insects and animals, are all potential sources of contamination. There is also a question mark over the possibility of bacterial growth taking place in the storage containers. Further on-going scientific and social scientific research into the causes of deterioration will be reported, and this will form the basis of sensible, practical recommendations that can be incorporated into water supply policy.

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Table 1: Geometric mean cfu/100ml in water samples measured at source and in household storage containers with calculated probability values.

Water supply type	Water quality at source (sample size)	Water quality in household storage container (sample size)	*P*-value
Hand-dug well	111 (108)	202 (334)	0.025
Borehole	1 (72)	72 (238)	<0.001
Comparison of household water by origin (borehole versus hand-dug well)			<0.001

Table 2: Classification of water quality samples according to the magnitude of contamination (adapted from Lloyd & Helmer, 1991).

Classification of microbial water contamination			Hand dug well		Borehole	
			Proportion (%) of samples according to risk category		Proportion (%) of samples according to risk category	
Grade	cfu/100ml	Risk	Supply point	Consumption point	Supply point	Consumption point
A	0	No risk	0	4	33	11
B	1-10	Low risk	10	4	48	18
C	11-100	Intermediate to high risk	33	16	19	15
D	101-1000	Gross pollution; high risk	47	49	0	36
E	>1000	Gross pollution; very high risk	10	27	0	20
			100%	100%	100%	100%

Table 3: Geometric mean cfu/100ml compared in (a) covered versus uncovered containers; (b) clay versus plastic containers; and (c) the correlation of stored water quality with hours stored.

Stored water origin	Storage characteristic (sample size)		*P*-value
(a)	**Container covered**	**Container uncovered**	
Hand-dug well	273 (115)	167 (57)	0.186
Borehole	154 (33)	213 (15)	0.736
(b)	**Clay container**	**Plastic container**	
Hand-dug well	224 (187)	384 (93)	0.057
Borehole	167 (24)	49 (8)	0.398
(c)	**Hours since collection FC/100ml**		
All stored drinking-water	Spearman Rank Correlation = -0.02		0.769