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Determinants of drinking water quality in rural Nicaragua

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SUMMARY

One hundred and fifty-three water samples from rural Nicaragua were examined for the presence of faecal coliforms during both wet and dry periods. A linear model was fitted by analysis of covariance with the logarithm of the faecal coliform count as the dependant variable. As expected, traditional water sources were grossly contaminated at all times whereas piped water sources were much cleaner. Hand-dug protected wells had significantly higher levels of faecal contamination than unprotected riverside wells and springs during the dry season. The possible reasons for this unexpected finding are discussed. A close association between rainfall and faecal contamination was demonstrated but the effect of rainfall depended on the type of water source. An association between water quality and the size of the community served by the source was also detected. The finding that stored water was usually more contaminated than fresh water samples is consistent with the results from other studies. Since it is unusual for water quality to be inversely correlated wth accessibility, this study site would be suitable for investigating the relative importance of water-borne versus water-washed transmission mechanisms in childhood diarrhoea.

INTRODUCTION

It is generally believed that the use of inadequate water supplies relates closely to the high incidence of childhood diarrhoea in most developing countries, in spite of the difficulties that have been encountered in measuring this relationship (Blum & Feachem, 1983; Esrey & Habicht, 1986). Diarrhoea, like all faecal–oral diseases, can be transmitted by both water-borne or water-washed mechanisms (Cairncross & Feachem, 1983). Water-borne transmission occurs when the pathogen is in water that is drunk by a person or animal which may then become infected. Improvements in drinking water quality will reduce water-borne transmission. In water-washed tansmission, domestic and personal hygiene plays a key role and therefore disease is prevented by increasing the quantity of water used for

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hygienic purposes, irrespective of the quality of that water (Cairncross & Feachem, 1983). It is still not known which of these transmission mechanisms is more important for diarrhoea (Feachem *et al.* 1978). Although most work suggests that improvements in water quantity are more likely to reduce the incidence of diarrhoea than improvements in microbiological quality (Esrey & Habicht, 1986; Briscoe, 1978; Esrey *et al.* 1985; Freij *et al.* 1978; Schliessman, 1959), at least one study has shown a greater benefit from water quality improvements, especially in younger children (Herbert, 1984).

The relative importance of these two transmission mechanisms has major implications in the design and construction of rural water supplies. Although water supply projects often increase both the quality and quantity of water used, such interventions are usually very expensive. It is now becoming clear that it is beyond the economic ability of most developing nations to provide sophisticated water supplies to entire populations (Schneider *et al.* 1978; Walsh & Warren, 1979).

On the other hand, there are several relatively inexpensive interventions which might independently improve either water quality (e.g. simple chlorinators or filtration systems) or increase water consumption (e.g. hand pumps and well digging). This paper presents the results of a study of the microbiological quality of drinking water sources in rural Nicaragua which will be used in the analysis of a case-control study of the relationship between water quality, water accessibility and childhood diarrhoea.

MATERIALS AND METHODS

The study site was Villa Carlos Fonseca, a rural municipality on the Pacific coastal lowlands with a population of approximately 20000 spread amongst 35 communities. A population-based survey of the zone was made from a random sample (stratified by community) of 244 (6·7%) of the households on record with the Ministry of Internal Commerce whose consumer census is the most up-to-date population census available. Ministry officials estimate its completeness to be approximately 95%. Each of the houses selected was visited by a trained interviewer who interviewed the female head of household. The water supply for the household was ascertained and inspected. It was thereby possible to classify the different types of water source and to estimate the proportion of the population using each of them.

Sites for monthly water-sampling were chosen at random for each type of water-supply identified in the population-based survey. Additional water samples were also randomly selected at different times to provide sufficient statistical power to test diverse hypotheses. Water samples were collected in sterile glass bottles and transported to the laboratory in a cold box containing freezer packs. In all cases, analysis by the multiple tube method was commenced within 8 h of collection. The glassware and media were sterilized the day before in an autoclave at 121 °C for 15 min. Five sets of five tubes were inoculated with 10, 1, 0·1, 0·01 and 0·001 ml of each sample. Samples were incubated first in lauryl tryptose broth (Gibco Laboratories no. 28300) for 24 h at 37 °C in a warm-air incubator. Positive tubes were confirmed by inoculating a further set of tubes containing *E. coli* medium

Table 1. *Population and water sample distribution by water source*

Water source	Population served (%)	No. of sources tested	No. of samples taken: Wet period	Dry period	Total
Rivers or streams	2·5	5	3	16	19
Unprotected wells and springs	26·3	13	6	25	31
Protected bucket wells	52·5	15	5	37	42
Protected wells with pumps	2·0	7	0	11	11
Public standpipes	1·7	3	3	21	24
House connections	15·0	7	3	23	26
Total	100	50	20	133	153

Table 2. *Parameters included in the water quality model*

Variable name (and type)	Range of values
Main effects	
Type of water source*** (categorical)	1 = rivers/streams 2 = unprotected wells 3 = protected bucket wells 4 = protected wells with pumps 5 = public standpipes 6 = house connections
Rainfall period** (dummy)	0 = dry period (July–December) 1 = wet period (mid-May–June)
Community size* (dummy)	0 = small ($\leqslant$ 1500 inhabitants) 1 = large ($>$ 1500 inhabitants)
Storage*** (dummy)	0 = fresh sample 1 = sample from storage vessel
Interactions	
Type of water source by rainfall**	

$*P < 0{\cdot}05$; $**P < 0{\cdot}01$; $***P < 0{\cdot}0001$.

Table 3. *Geometric mean faecal coliform counts by water source for each weather period*

Water source*	Weather period: Wet period	Dry period
Rivers and streams	14700	11100
Unprotected wells and springs	15250	179
Protected bucked wells	4300	1410
Protected wells with pumps	No samples taken	22
Public standpipes	19	11
House connections	2	0

* Does not include stored water samples

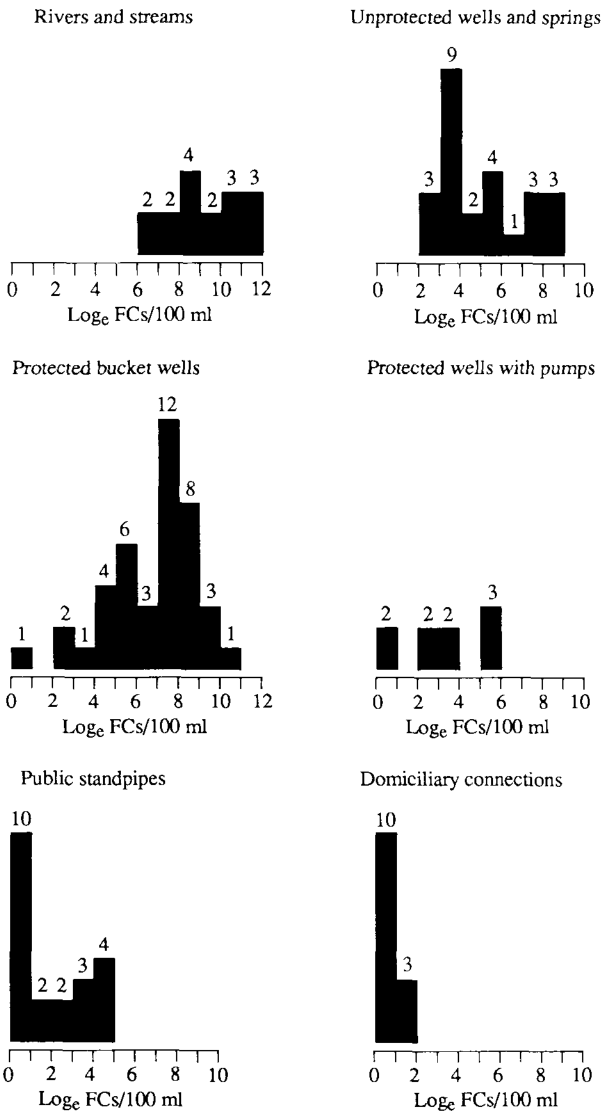

Fig. 1 (*a*). Histograms of geometric mean faecal coliform counts by water source for the dry period.

(Difco Laboratories no. 0314-01-0) and incubating these at 44·5 °C in a water-bath for an additional 24 h. Most probable number faecal coliform (FC) counts were calculated from the proportion of tubes at each dilution confirmed as positive, that is gas-producing (APHA, 1981).

A linear model was fitted by analysis of covariance with the natural logarithm of the FC counts as the dependent variable. The independent variables considered were: type of water source, recent rainfall, time of sampling (morning or afternoon), presence of a windlass on protected wells, whether the sample was 'fresh' or stored and size of the community from which the sample was taken. The latter was considered large if communities were of greater than 1500 inhabitants.

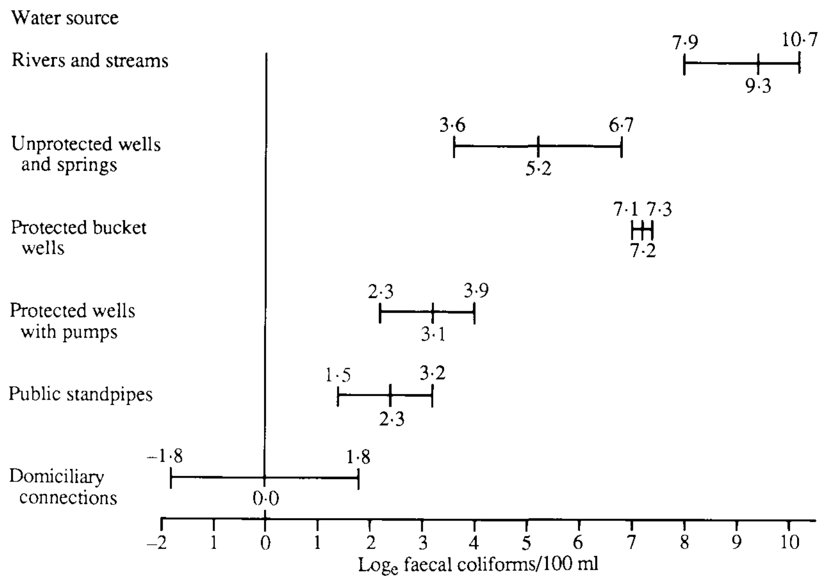

Fig. 1 (*b*). Geometric mean faecal coliform counts with 95% confidence limits by water source for the dry period. N.B. Does not include wet period or stored water samples.

It was thought that this might be an adequate surrogate for population density, especially since the houses in the communities of this size were arranged in street blocks whereas smaller communities consisted of a single main road with occasional side streets. Pairwise comparisons were made using the Tukey–Kramer studentized range test to control for type I experimentwise error (Einot & Gabriel, 1975).

RESULTS

Trained field-workers were successful in interviewing female heads of household at 240 (98%) of the homes selected. Water supplies were classified into five main types: domiciliary connections, public standpipes, protected wells, unprotected wells and springs, and rivers or streams. The domiciliary connections in one area functioned for less than 4 h per day, but the rest provided water virtually all day and were quite reliable. All public piped water came from boreholes, there being three different boreholes providing water to standpipes and another two different boreholes supplying the networks of domiciliary connections. The protected wells were hand-dug, generally to a depth of about 4 m, and were surrounded by a precast concrete headwall. As a rule they were partially lined by stone which was sometimes joined to the headwall by mortar. Water was drawn in a bucket on a rope supported by a crossbar and pulley. Many were roofed and some had a windlass, but none incorporated a drainage apron. They were usually privately owned and sited in the yards of peoples homes. Springs and unprotected wells were shallow holes in the ground usually adjacent to rivers in which water accumulated either by filtering up from below or by seepage from above (or both). They were

Table 4. *Geometric mean faecal coliform counts by water source and community size*

Water source*	Community size† Large	Community size† Small
Rivers and streams	27800	5760
Unprotected wells and springs	767	83
Protected bucked wells	1450	977
Protected wells with pumps	16	39
Public standpipes	No samples taken	7
House connections	0	5

† There were 3 communities considered to be large and 16 communities classified as small.
* Does not include wet period or stored water samples.

often carved out from sandstone. As the springs and unprotected wells formed an indistinguishable continuum they will both be referred to as unprotected wells. None of the water supplies were treated.

The proportion of houses with each type of water source is shown in Table 1 together with the number of water samples taken from each. The number of samples taken during the wet period is low due to the drought in 1986 which greatly reduced the length of the wet season.

The complete model fitted is shown in Table 2, together with the significance level for each variable. Only those interactions found to be statistically significant are shown. In fitting the model, each monthly measurement of a single source is considered as an independent sample as it was noted that there was almost as much water quality variation for repeated samples from the same site as there was for different samples from different sites.

Geometric mean FC counts of each water source for the wet and dry periods are shown in Table 3. All mean values quoted are 'least squares means' which adjust the estimates to allow for the unbalanced design. There were not enough samples taken during the wet period to permit pairwise comparisons but the quality of piped water is obviously much better than that of traditional sources. It would be interesting to obtain sufficient samples during this period to test whether protected wells are less contaminated than the unprotected sources. For the dry period, the distribution of FC counts by water source is plotted in Fig. 1*a*. Pairwise comparisons were made using the Tukey–Kramer studentized range test (Fig. 1*b*).

The nature of the water source/rainfall interaction can be seen in Table 3. While the quality of water drawn from springs and unprotected wells improves strikingly in the dry period, the quality of other sources did not change greatly. Unprotected wells and springs seem to be more contaminated than protected wells during the wet period, but they are significantly less contaminated during the dry period.

Table 4 shows for each type of water source how the quality depends on the size of the community from which the water was sampled. The quality of piped water sources does not depend on the community size but it appears that the quality of traditional water sources does. In fact for piped water, quality seemed to improve in the larger communities but this difference is unlikely to be significant.

As indicated in Table 2, water stored in homes is significantly more contaminated than water drawn directly from the source. The geometric mean FC count of stored water from domiciliary connections was 94 compared with 0 for the unstored samples. There were not enough samples to determine how domestic storage affects water drawn from other sources.

Of the 42 samples taken from protected bucket wells, 6 were taken from wells incorporating a windlass. It was hypothesized that the presence of a windlass on a protected well would reduce the contamination since the rope does not drag on the ground. In fact, the (least squares) geometric mean FC count of those wells with a windlass was 1420 compared with 1100 for those without ($P = 0{\cdot}77$), though caution should be excercised in interpreting this result owing to the small number of samples from wells with a windlass.

DISCUSSION

In many ways this analysis confirms the results obtained from several other studies in that the quality of water was found to depend greatly on the type of water source from which it is drawn, the weather prior to the time of sampling, and whether it was taken directly from the source or from a storage vessel in the home (Freij *et al.* 1978; Schneider *et al.* 1978; Shiffman *et al.* 1978; Young & Briscoe, 1987; Muhammed & Morrison, 1975; Torun, 1982; Barrell & Rowland, 1979). It does not pretend to take into account all the variables that have been considered in other work (e.g. soil type, well diameter, depth, distance to the nearest latrine, etc.) and there are other variables which might affect the water quality of domestic wells which have not generally been considered in this type of study (e.g. literacy, presence of domestic animals, etc.).

As in other studies, there is a very high level of contamination in the traditional water sources. The unexpected finding was that protected domestic wells were significantly more contaminated than unprotected riverside wells and springs during the dry period. Most studies of rural water quality have found that protected sources are generally less polluted than unprotected sources. Tomkins *et al.* (1978) and Wright (1982) both found that protected wells were less contaminated than unprotected wells during the dry season. Isely (1978) and Lehmusluoto (1987) also both found protected springs to be less contaminated than unprotected springs though in the latter study the difference was not statistically significant. On the other hand in Nigeria Blum *et al.* (1987) found significantly lower faecal streptococci counts in ponds and unprotected springs than in traditional wells during the period of lower contamination, but it was not clear how well protected their 'traditional wells' were.

There are two possible explanations for the observed difference in water quality between the protected and the unprotected sources. One is that the protected wells are exposed to greater faecal contamination in spite of their protection. The other is that a structural difference tends to make the unprotected water sources less polluted during the dry period.

The first hypothesis is supported by the fact that protected wells in this part of Nicaragua are almost all privately owned and located close to houses where children and domestic animals defecate openly. Also, 72% of these wells are in homes with latrines although most of them are situated at least 10 m from the well (Sandiford *et al.* unpublished results). In contrast, the unprotected wells are usually dug beside rivers and streams 50–100 m from the nearest houses.

It would seem unlikely that a structural difference could explain why unprotected wells have lower FC counts during dry weather than protected wells. Protected wells all have parapets at least one metre high, they usually incorporate a crossbar and pulley, and often have a roof, a cover, and/or a windlass, while unprotected wells are much shallower and do not have parapets. One important feature of the unprotected well though, is the small volume of water which it holds (usually only 20–40 l). As each generally serves several families, the high demand for water creates a rapid turnover which would readily eliminate externally introduced contaminants. It has been observed that some families empty these wells and allow them to refill each time they collect water (Pauw *et al.* in preparation). The protected wells on the other hand, contain a much greater volume of water which is emptied by their owners only once or twice a year.

Though more research is needed to determine the relative importance of these two explanations the quality of water from protected wells does appear to be more variable than that from unprotected wells (Fig. 1*a*) suggesting that certain factors in the domestic environment may give rise to contamination. Not all protected wells had higher counts than unprotected wells.

It is notable that the presence of a windlass appeared to have no effect on the water quality of domestic wells. Those with an electric pump to extract the water were significantly less contaminated than those using a bucket and rope, in spite of being virtually identical in other respects. It is possible that much of the contamination of protected bucket wells originates from water spilt around the parapet seeping back into the well. Pumps which pipe water away from the well clearly avoid this problem. The complete absence of drainage aprons in the Nicaraguan wells studied makes them rather susceptible to this type of pollution (Cairncross & Feachem, 1983).

The poor quality of springs and unprotected wells during periods of rainfall is probably due to run-off into the wells. Similar problems have been noted with unprotected springs in other studies (Moore, de la Cruz & Vargas-Mendez, 1965; Barrell & Rowland, 1979). It would be interesting to investigate the impact of spring protection during the rainy periods. A modest drop in the quality of domestic well water was also noted with the rainfall which is consistent with other studies (Voelker & Heukelekian, 1960; Barrell & Rowland, 1979).

Community size was found to be significantly associated with water quality and this was particularly noticeable in the rivers, springs and unprotected wells. An association between water contamination and proximity to towns has previously been reported (Muhammed & Morrison, 1975; Bradley & Emurwon, 1968) but only for rivers and streams. It may be that the more families using a source, the greater the potential for contamination. In fact the mean number of houses using unprotected wells and springs in large communities is 4·2 compared with 2·9 in smaller communities (Sandiford & Gorter, unpublished results).

Community size did not seem to affect the quality of protected well water where an average of 2·2 families are served by each well in both small and large communities.

This study has shown that water quality in protected wells is not always better than that in unprotected wells, though the reasons are not entirely clear. More research is needed to determine the most cost-effective means of protecting hand-dug wells. If cheap but effective structural modifications to traditional water sources can be found, these may prove to be appropriate interventions for the prevention of water-borne illnesses.

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